The Scholars Programme

Symmetry, Symmetry Breaking and Why the Universe Doesn't Annihilate Itself

Key Stage 4 Programme

Pupil Name	
Coursebook Designed by	Lauren Martin

Timetable and Assignment Submission

Timetable – Tutorials

Tutorial	Date	Time	Location
1 (Programme Launch)			
2			
3			
4			
5			
6 (Draft assignment feedback)			
7 (Final assignment feedback)			

Timetable – Homework Assignments

Homework Assignment	Description	Due Date
Tutorial 1	Baseline assessment	
Tutorial 2		
Tutorial 3		
Tutorial 4		
Tutorial 5	Draft assignment	
Tutorial 6	Final assignment	

Assignment Submission – Lateness and Plagiarism

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

KS4 Programme – 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 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

Name of PhD Tutor			
Title of Assignment			
Name of Pupil			
Name of School			
ORIGINAL MARK / 100		FINAL MARK / 100	
DEDUCTED MARKS		FINAL GRADE	

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

Knowledge and Understanding	**Research and Evidence**
=	*Enter feedback here*
Developing an Argument	**Critical Evaluation**
=	*Enter feedback here*
Structure and Presentation	**Language and Style**
=	*Enter feedback here*

Overall Comments (participation, effort, resilience)
=

Contents

Course Rationale

Physics is the most fundamental of the sciences. To study physics is to pit your wits against nature. In studying physics, we want to find out exactly where the universe came from and how it works. It is a subject which is often full of surprises; as soon as we think we've got things all figured out a new observation will teach us how much we still have to learn.

Ever since Einstein discovered his theory of relativity symmetry has been at the very centre of modern physics. In this course we're going to learn exactly what scientists and mathematicians mean when they talk about symmetry and why it is so important in understanding the universe. We'll go on to look at one of the most important symmetries of space and time - the invariance of the speed of light. We'll go on to see that based on this simple symmetry clocks (and in fact time itself) must run slower (time dilation) when we move really fast. We'll look at the symmetry between matter and anti-matter and we'll use Einstein's most famous equation to see how we can both create and destroy particles and explain why the universe is full of matter. We'll also look at how some symmetries must be 'broken' (not perfect) and why if they were not, we'd be living in a completely empty universe!

As you progress through this course, you'll develop your mathematical and analytic skills as well as your ability to carry out independent research and communicate your findings. By the time you come to complete your final assignment you'll be able to carry out university level calculations in Einstein's theory of special relativity which apply to real world situations. You'll be able to combine the ideas presented in this course with your own research to effectively convey the importance of symmetry in modern physics and discuss the most important symmetries in detail. In doing this you'll be developing analytic, research and quantitative skills and your ability to think outside the box and look at situations from a new perspective. It is these problem solving skills and the ability to communicate complicated ideas effectively which make people who have studied difficult subjects like these so in demand not just in scientific fields but also throughout finance, engineering, politics, advertising and countless other areas.

Group Discussions

How do you make the most of a group discussion?

The purpose of discussions is to allow everyone in the group to express their ideas and learn from each other. Often this will involve coming to a group decision about the issue under discussion, though they may of course 'agree to disagree' on certain points.

What we don't want in our tutorials:

Artwork by MiaHague.co.uk

Rules:

1. Pronounce clearly what you are saying
2. Use eye contact and facial expression to help to get your idea across or to support what someone else is saying
3. Speak in a way that is right for a discussion (more formal than a chat between friends)
4. Build on other people's ideas, and summarise your own views and the views of others when necessary
5. Give reasons to support your views and critically examine the views expressed by others
6. Organise the discussion and take turns with others
7. Listen carefully and respond to the views of others

Mark Scheme Table

Skills	1st (70-100)	2:1 (60-69)	2:2 (50-59)	3rd (40-49)	Mark /100
Knowledge and Understanding	○ Sophisticated understanding of the course material. ○ All the content included is relevant to the general topic and final assignment question – this shows clear thought about what to include. ○ Good evidence of independent thought. ○ Clear thought about unanswered or unexplored questions. ○ Very few factual mistakes. ○ Correct scientific language used, defined when it is useful to do so.	○ Good understanding of the course material. ○ Content included is usually relevant to the general topic and final assignment question. ○ Some evidence of independent thought. ○ Some attempt to think about unanswered or unexplored questions. ○ Very few factual mistakes. ○ Correct scientific language usually used, defined when it is useful to do so.	○ Mostly a good understanding of the course material. ○ Content included is usually relevant to the general topic and final assignment, but some may have been included without a clear reason. ○ Some evidence of independent thought. ○ Little attempt to address unanswered or unexplored questions. ○ Some factual mistakes. ○ Sometimes uses the correct scientific language but rarely includes definitions.	○ Some understanding of the course material. ○ Some of the content included is relevant to the general topic and final assignment, but some may have been included without a clear reason. ○ Little evidence of independent thought. ○ Does not attempt to address unanswered or unexplored questions. ○ Some factual mistakes. ○ Can use the key scientific language, but only uses this correctly occasionally and rarely include definitions.	
Critical Evaluation / Problem Solving	○ Always chooses research evidence that is related to and appropriate for the arguments made. ○ As well as describing the evidence, always explains its value or significance. ○ Often comments on how reliable the sources are, including potential limitations. ○ Evaluation is always clear, easy to follow and explained.	○ Often chooses research evidence that is related to and appropriate for the arguments made. ○ As well as describing the evidence; usually explains its significance. ○ Sometimes suggest why a source is/ is not reliable. ○ Evaluation is usually clear, easy to follow and explained.	○ Sometimes chooses research evidence that is related to and appropriate for the arguments made ○ Consistently describes evidence and sometimes attempts to explain its significance. ○ Can say if a source is reliable or not but does not always explain this. ○ Evaluation is not always clear, easy to follow, or explained.	○ Rarely chooses research evidence that is related to the arguments made. ○ Consistently describes evidence but does not always explain its significance. ○ Can say if a source is reliable or not but does not always explain this. ○ Evaluation is rarely clear, easy to follow, or explained.	
Structure and Presentation	○ Introduction clearly outlines what the assignment will contain. ○ Organises ideas in paragraphs with a logical structure that makes it easy for the reader to follow. ○ Excellent answering of the question. ○ Conclusion summarises all of the main points clearly. ○ Where needed, includes the correct units.	○ Introduction outlines what the assignment will contain. ○ Organises ideas in paragraphs with quite a clear structure that makes it easy for the reader to follow. ○ Good answering of the question. ○ Conclusion summarises most of the main points clearly. ○ Where needed, includes the	○ Introduction briefly outlines some aspects of the assignment. ○ Organises ideas in paragraphs, but their order could be more logical to make it easier for the reader to follow. ○ Attempts to address all aspects of the question. ○ Conclusion summarises some of the main points. ○ Includes units where needed, but with some errors.	○ Introduction mentions the main issue. ○ Usually organises ideas in paragraphs, but their order is not always easy for the reader to follow. ○ Does not address all aspects of the question. ○ Conclusion summarises some of the main points. ○ Often forgets to include the correct units. ○ Sometimes forgets	

	○ Tables and graphs are labelled correctly, including titles and units. ○ Demonstrates an excellent understanding of referencing – all sources are cited in text and referenced in the correct format.	correct units. ○ Includes most of the appropriate labels for tables and graphs, including titles and units. ○ Demonstrates a good understanding of referencing – most sources are cited in text and referenced in the correct format.	○ Includes some of the appropriate labels for tables and graphs, including titles and units with occasional errors. ○ Demonstrates a developing understanding of referencing – some of sources are cited in text and referenced correctly, but with errors.	to include the labels needed for tables and graphs, such as titles and units. ○ Has not or only occasionally attempts to reference.	
Overall mark for the written element (average of the 3 marks from the above criteria) /100					
Problem set mark /100					
Final mark *(Mark for written element + Problem set mark)* ÷ 2 /100					

Glossary of Keywords

Word	Definition	In a sentence
Symmetry	A feature of a system which remains unchanged under a certain transformation.	If a picture has rotational symmetry of order 3 and you rotate it through a full circle there will be three occasions where it looks exactly the same.
Discrete Symmetry	A symmetry which involves non-continuous transformations of a system.	Reflective symmetry is a discrete symmetry.
Continuous Symmetry	A symmetry which involves continuous transformations of a system.	Translational invariance is a continuous symmetry
Time Dilation	The difference in the time elapsed as measured by systems which are moving relative to each other.	Due to the effect of time dilation muons created in the upper atmosphere can reach the earth's surface before decaying.
Anti-matter	Matter made up of anti-particles as opposed to particles.	Anti-matter makes up a tiny proportion of the mass in the universe.
Anti-Particle	Particles which have exactly the same mass (and other properties) as their matter equivalent but have opposite charge.	The anti-matter partner of the electron is the positron.
Annihilation	The process by which a particle interacts with its corresponding anti-particle and their combined mass is converted into energy.	An electron and positron will annihilate leaving no matter and only energy.
Pair production.	The process by which if sufficient energy is provided a particle and its corresponding anti particle can be created.	The energy required for pair production, anti-particle pair depends on the mass of the particle.

Charge Conjugation	The transformation which changes a particle into its corresponding anti particle.	The universe is not invariant under charge conjugation.
Parity Transformation	The transformation which transforms everything into its mirror image.	Under the parity transformation my left hand would become my right hand and vice versa.
Inertial reference frame	A reference frame which is not accelerating or under the influence of a gravitational field.	In an inertial refence frame, an object will remain stationary or continue to move at a constant velocity unless a force is applied.

Mathematical Background.

Relatively little background mathematical knowledge is required for this course and might already be familiar to you. The main points are detailed below.

Standard form and index notation

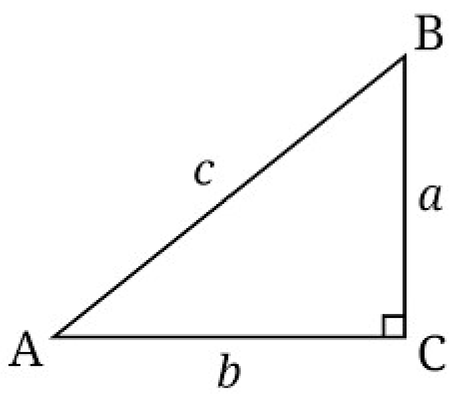
When writing very large or very small numbers it can be cumbersome to write and difficult to read if we include lots of zeros (for example 40000000000). In this case we write numbers in 'standard form'. This simply means writing the large or small number as a number between 1 and 10 multiplied by a power of 10. A positive power of ten denotes how many times the number must be multiplied by 10 and a negative power of 10 denotes the number of times the number must be divided by 10.

For example:

$34000000 = 3.4 \times 10^7$

$0.00056 = 5.6 \times 10^{-4}$

Pythagoras' theorem



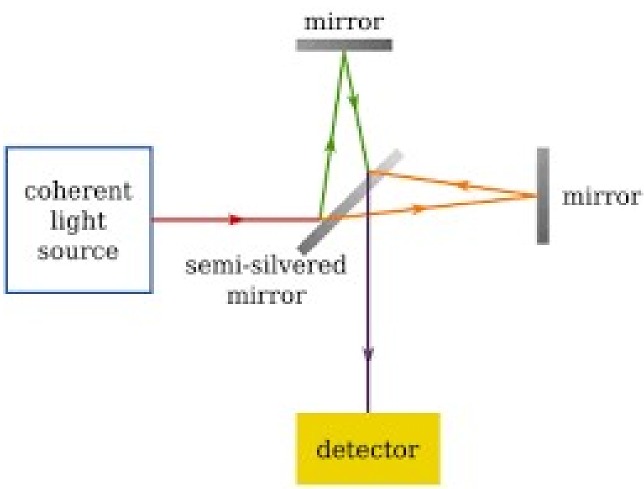
According to Pythagoras' theorem in a right-angled triangle:

$$a^2 + b^2 = c^2$$

Where c is the length of the hypothenuse of the triangle (the hypotenuse is the side opposite the right angle so is the only side of the triangle not connected to the right angle) and a and b are the lengths of the other two sides (it doesn't matter which you call a and which you call b).

Relevant Experiments

The Michelson Morley Experiment.



This was an experiment performed in 1887. It had previously been assumed that the universe was filled with an invisible material called 'ether' (similar to the atmosphere on earth). This material would provide an objective frame of reference for the universe as you could always measure your velocity relative to the ether. It was assumed that the ether would provide a medium through which light would travel (just like air provides a medium through which sound waves travel and the sea provides a medium through which water waves travel). Since it is known that the earth is travelling through space (because it is orbiting the sun at around 30,000 m/s and also because the entire solar system is orbiting the centre of the galaxy at around 100,000 m/s) it was assumed that the time taken for the light to pass through the experimental set up would depend on the direction of travel of the light relative to the direction of travel of earth. For example if I was at sea in a boat and saw a large wave travelling towards me the time taken for the wave to reach me would depend on which direction the boat was travelling in relative to the wave. If I travelled directly towards the boat it would reach me more quickly than if I steered my boat at a direction at $90°$ to the direction of closes approach of the wave, if I drove my boat directly away from the wave it would take longer still for the wave to catch up with me.

In the experiment the light was split at the semi-silvered mirror so half of the light would travel in one direction and the other half would travel at $90°$to that direction. The separate beams of light would then be reflected by mirrors back to the semi-silvered mirror where they would both pass through the mirror recombing and eventually reaching a detector. Since the two separate beams of light should be travelling in different directions relative to the velocity of the earth they should take different times to traverse the experimental set up. By the time they were recombined they would then be 'out of phase' which would cause an interference pattern to be observed at the detector. However no evidence of any interference could be observed so the light from both beams must have taken exactly the same time to travel through the experiment.

CP Violation: Experimental Evidence

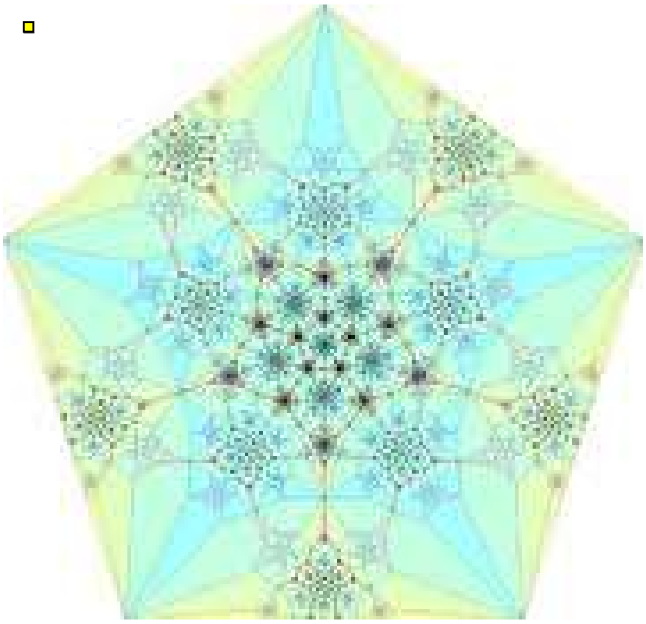
The first experimental evidence for CP violation was observed in 1964 in an experiment carried out by Cronin and Fitch (for which they were awarded the Nobel prize).

The experiment involved neutral kaon particles. A kaon is not a fundamental particle but is made up of smaller particles called quarks. A neutral kaon is made up of a down quark and an anti-strange quark. Its anti-particle is therefore made up of an anti-down quark and a strange quark.

The neutral kaons can decay to either two or three pions. however, the decay to two pions happens much more quickly with a lifetime of 10^{-10} seconds, whereas the decay to the three pions has a lifetime of around 5×10^{-8} seconds (500 times longer). Cronin and Fitch directed the kaons down a 17m beam line. The shorter-lived kaon should decay very quickly (within a few cm) meaning that towards the end of the beam line only the longer-lived kaon would remain (and only decays to three pions would therefore be observed). However, a small number of two pion decays were observed at the end of the beampipe. This provides evidence that neutral kaon particles can transform into their anti-particles and vice versa. However, this change does not happen equally in both directions and therefore provides proof of CP-Violation.

From 1990 onwards other evidence of CP violation has been observed. The later evidence involves 'direct CP-Violation'. This evidence is based upon measured the decay rate of a particular decay. Then measuring the decay rate of the CP decay (i.e. the same decay involving antiparticles rather than particles) It has been observed that for some decays one decay rate is slightly larger than the other which again provides proof of CP violation. However, since the level of CP violation in these cases are very small, high precision measurements are required.

Tutorial 1 – Symmetry Overview

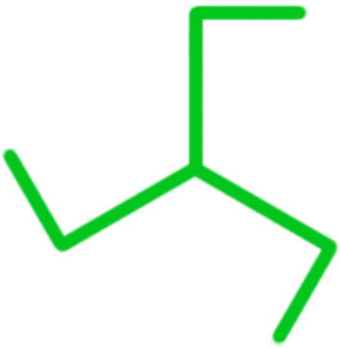


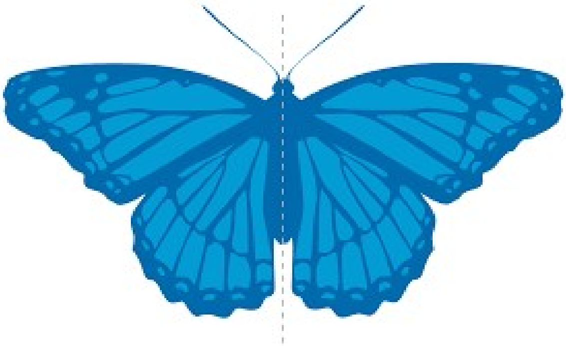
What is the Purpose of Tutorial 1?

- Understand formally what is meant by the term symmetry in maths and physics.
- Be able to identify symmetries in images and distinguish between discrete and continuous symmetries.
- Understand why symmetries are important in physics.
- Be able to describe Noether's theorem and give some examples of the symmetries and associated conservation laws.

Starter Activity: Symmetry in images

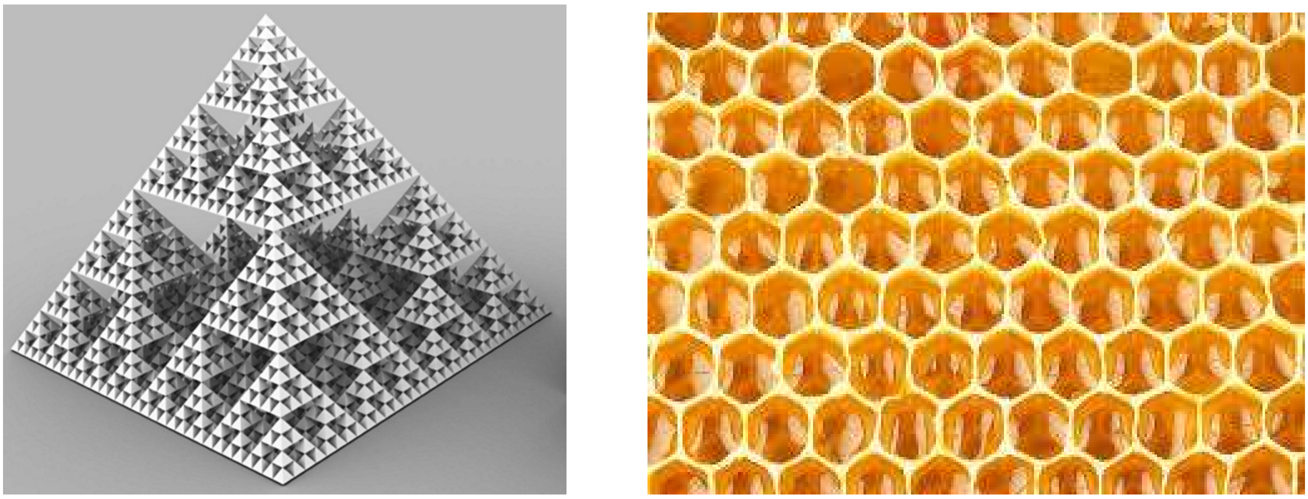
Identify the symmetry (if any exists) in the following pictures.





Both pictures can be described as possessing a form of symmetry but not the same form. Can you think of a way to describe what symmetry means in general?

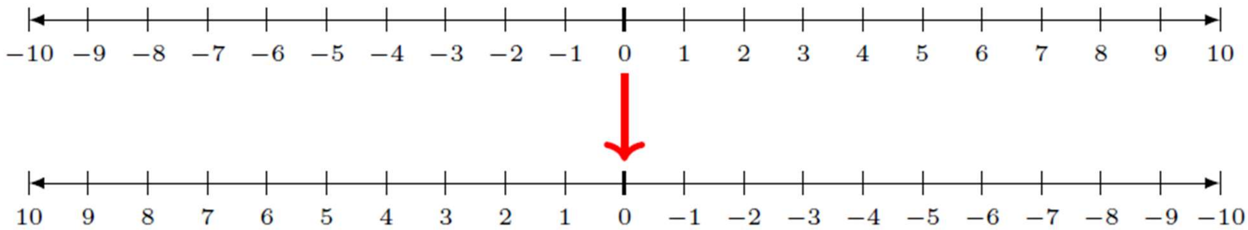
Fig. 2



Imagine the above pictures going on forever, can you identify one type of symmetry for each picture?

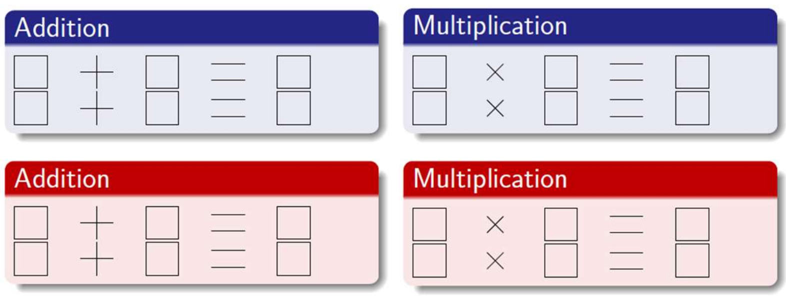
The symmetries above are described as 'discrete symmetries' because only certain non-continuous changes (for example rotating by a set number of degrees) keeps the picture the same. Can you think of a shape with continuous symmetry?

Symmetry in Maths



Consider the number line above which has been reflected about 0. Every positive number becomes negative (e.g. 2 becomes -2) and vice versa (-5 becomes 5).

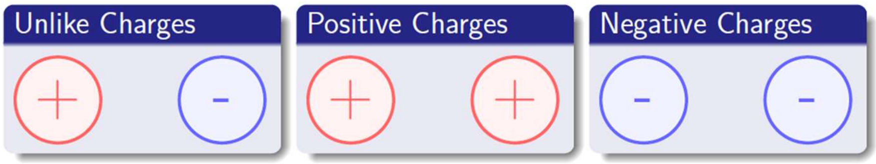
Is mathematics symmetric under such a reflection?



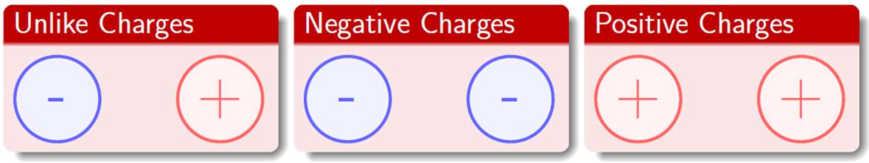
Think of examples of correct addition and multiplication sums and fill in the blue boxes (include both positive and negative numbers). Then transform these according to our above transformation. Fill in the transformed calculation in the red box. Are they still correct? What can we say about the symmetry of addition and multiplication under our transformation?

Symmetry in Physics

Electromagnetism is one of the four fundamental forces of physics. Under electromagnetism like charges attract each other and unlike charges repel.



In the above picture draw with arrows the direction of the force on each of the charges in the blue boxes.
In the pictures below we have transformed the charges by exchanging positive particles for negative and negative for positive.



Will the direction of any of the forces change?

Is Electromagnetism symmetric under this transformation?

In physics reversing the charge of a particle while keeping the other properties of the particle (for example its mass) the same is a significant process. It is called 'Charge Conjugation' (or C for short) and under this process we change particles into anti-particles.

Physicists are especially interested in this symmetry because charge conjugation symmetry would contradict a key experimental observation in the universe: If the universe is symmetric under charge conjugation then the number of particles and anti-particles in the universe should be equal. This is definitely not the case! Everything we see around us (in this room, in the solar system and the wider universe) is made of matter not anti-matter. Only 0.0000001% of the universe is made up of anti-matter. Later in this course we'll look at the 'matter anti-matter asymmetry problem' in more detail.

The importance of symmetry in physics: Noether's theorem

What symmetries do we expect to see in the universe?

Do we think the laws of physics will change according to where we are in the universe? This is called translational symmetry as it's related to translating our position in the universe. If I performed an experiment in the solar system would I get the same result as if I performed the same experiment under the same conditions in a different galaxy?

Will the laws of physics change, depending on which direction we're looking in? If I rotated my entire apparatus would my experiment give me the same results?

Do the laws of physics change with time?

Will the laws of physics change if we changed the scale factor (for example if we suddenly made everything twice as large)?

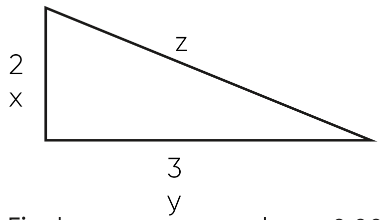
The question of symmetries may seem arbitrary but in 1915 it was proved by Emmy Noether that for each continuous symmetry of the universe there is a corresponding conserved quantity. This is known as 'Noether's theorem'. For example, it can be proved that the translational symmetry of the universe leads to the conservation of momentum. The invariance under time translations leads to the conservation of energy and the rotational symmetry leads to the conservation of angular momentum.

Homework: Baseline Assessment

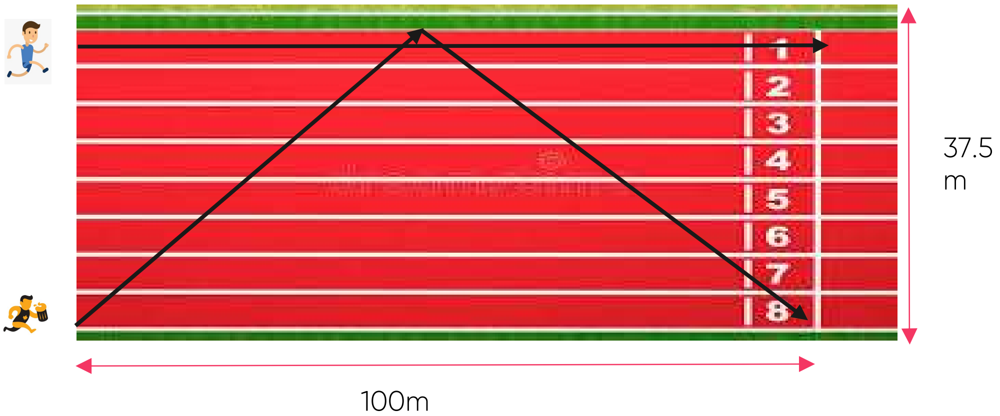
Produce a short piece of writing (approximately 150-400 words) formally introducing the concept of symmetry. You should describe what is meant by both continuous and discrete symmetries and give examples (either from the tutorial or if possible further examples which you have researched or thought about yourself) including diagrams where possible. Describe examples of symmetries within physics and give a qualitative description of Noether's theorem. You might include a brief description of who Emmy Noether was (when she lived and how she came to develop her theorem).

Problem Set.

1) See the diagram of a right angle triangle. Using pythagoras' theorem calculate the length z in terms of x and y.

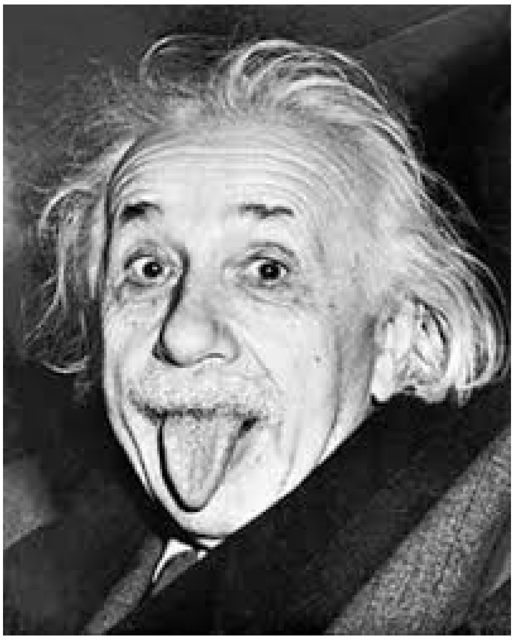


2) Find x where $0.000067 = 6.7 \times 10^{x}$
3) Find y where 460000000 = 4.6×10^{y}
4) Two men are running along a 100m track. Both maintain a steady pace of 5 meters per second. The first travels in a straight line. How long will he take to complete the 100m distance?
5) The second man takes a (symmetrical) diagonal course as shown in the diagram. Calculate how far he needs to travel to complete the race. How long will it take him to complete the race?



6) I'm standing on a platform while a train slowly travels past at 10m/s. A person on the train is walking up the carriage towards the front of the train at 1m/s. How fast is the person moving relative to me?
7) The person now changes direction and walks at the same speed towards the back of the train how fast are they now moving relative to me?
8) The tennis player John Isner holds the world record for the fastest ever serve at 157 miles per hour. For reasons we haven't been told he is standing on top of a train travelling at 120 miles an hour. He serves a ball from the train. In the opposite direction to the direction of travel of the train. How fast is the ball travelling relative to an observer not on the train?
9) Consider the transformation of numbers $x \rightarrow x^2$. (i.e. each number is transformed into its square). Which number is invariant (doesn't change) under this transformation? Would this transformation be symmetric under addition? Multiplication?

Tutorial 2 – Special Relativity and Time Dilation



What is the Purpose of Tutorial 2?

- Understand how time dilation naturally arises from the invariance of the speed of light (which is understood as a symmetry of space and time).
- Perform calculations to show how much time will have elapsed according to a clock in a moving reference frame.

It's all relative: Special Relativity

Do you think the laws of physics are constant in time? (Would our experiments have given us different results if we'd carried them out thousands of years ago, what if we repeated the same experiments thousands of years in the future?).

We call this time translation symmetry. By looking at light from distant galaxies we are seeing the universe as it was billions of years ago and we have observed the same 'hydrogen spectra' as we observe today which suggests the same laws of physics apply.

Do you think the laws of physics are the same throughout the universe? If we repeated all of our experiments in a distant galaxy, would we get the same results?

We call this spatial translation symmetry.

What about the speed at which we're moving when we perform our experiments? Will that affect our results? (This is called Lorentz Symmetry)

Have you ever sat on a stationary train next to a moving train and you couldn't tell which train was moving? How did you tell who was actually moving?

What would happen if instead of sitting on a train at a platform you were sitting in a spaceship in empty space next to another rocket moving relative to you. You now have no frame of reference to compare to. Would there be any way of deciding which of you was actually moving and which was stationary?

Imagine you're on a train and drop a ball from your full height. Will the ball land in a different place on the carriage floor depending on the speed of the train?

This idea is at the heart of special relativity. According to special relativity there is no experiment you could do in a rocket (or other moving reference frame) which would determine whether or not you're moving and how fast. This is because the universe has no fixed, stationary reference frame to compare to. As long as you're travelling at constant speed the laws of physics and all of your experimental results will remain exactly the same.

One of the most important laws of physics which has been experimentally verified to very high precision is described by 'Maxwell's equations'. These equations describe how light, charged particles (and therefore electricity) and magnetism behave. According to Maxwell's equations the speed of light is constant. Therefore, however fast we move we should always measure light travelling at the same speed.

This idea is at the heart of Einstein's special relativity. However fast we move we can never catch up with light. It will always move away from us at the same speed.

Special relativity gets its name because it's a 'special' case. It only applies to constant motion with no acceleration or gravity. We can call a reference frame without gravity or acceleration as an 'inertial frame'.

Postulates of Special Relativity

The postulates (or assumptions) of special relativity are actually very simple:

1) The laws of physics are the same in all inertial reference frames (there's no way of detecting if your reference frame is moving at a constant speed).
2) The speed of light is constant and independent of the relative speed of the source and observer.

What's so special about light?

Do you know the speed of sound in air?

Which aircraft (no longer in operation) famously broke the 'sound barrier'?

Can sound travel through the vacuum of space? Why?

Can light travel through the vacuum of space? Why?

Light is special because it doesn't need a medium to travel through. The vacuum of space once thought to be made up of an invisible material known as the ether is actually just a vacuum.

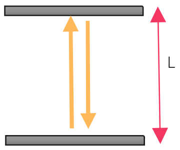
In fact, it's not just light which travels at this speed. This speed is an important property of space and time. It is the maximum speed at which anything (including information) can travel and anything which, like light, doesn't have any mass will travel at this speed.

Time dilation

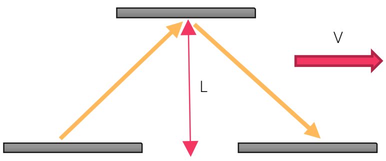
So far, we've decided that there's no way of determining how fast you're moving and that however fast you move the speed of light will always stay the same. Now we're going to see why that's interesting.

Let's think about time and how we measure it. Consider a very simple type of clock called a 'light clock'. The clock works by bouncing light between two mirrors. The 'tick' of the clock is the time it takes for the light to travel to the opposite mirror and back.

Now let's imagine you have one light clock in your spaceship, and I have an identical clock in my spaceship. Our spaceships are moving relative to each other, but we have no way of telling which one of us is moving and which, if either, is stationary.



Stationary Light Clock



Moving Light Clock

As far as I am concerned the clock in my spaceship is stationary and yours is moving since it's in your spaceship which is moving relative to mine.

How far will the light have to travel, in terms of L, to perform one tick of my stationary light clock? How long will it take the light to travel this distance (in terms of L and the speed of light, c)? We'll call this time t.

Now consider the 'moving' light clock. Let's call the speed of the spaceship 'v' and the time taken for one tick of the moving light clock t'. Therefore, the time taken to perform half a tick (i.e. to reach the other mirror will be t'/2).

In the time the light takes to reach the other mirror the mirror itself will have moved a horizontal distance (in terms of t' and v) and mark it on the diagram.

Using Pythagoras's theorem calculate the distance travelled by the light (in terms of L, v and t') to reach this mirror.

Therefore, calculate the total distance travelled by the light by the time it returns to the first mirror.

Given that the light is still travelling at constant speed c (and we know that distance = speed x time) Write the total distance travelled by the light in terms of c and t'.

Rearrange this equation to give t' in terms of v, l and c.

Hence write t' in terms of t (the time taken to perform a tick in the non-moving reference frame), v and c.

This expression is very important. We can rewrite it is as:

$$t' = \gamma t \qquad \text{where} \qquad \gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$$

The value of γ (called the 'Lorentz Factor') then tells us how many times longer the dilated time is compared to the time in the stationary reference frame, t. so basically γ tells us how much slower the clock is ticking due to its speed. Let's take a look at the values γ takes as we increase v.
What value will γ take when v = 0?

As we increase v from zero what happens to γ (does it increase or decrease)?

What happens to γ as v approaches the speed of light?

What would happen to γ if v became greater than the speed of light?

Is there a speed which would give a value of γ less than one?

If γ is always greater than 1 we can tell that t' will always be greater than t. That is to say if you're moving past me at great speed, I will always see your clock taking longer to perform a tick. Let's think carefully though with reference to the postulates of special relativity. If a clock in a moving reference frame started ticking slower, we would be able to tell that our spaceship was moving. Therefor it isn't that the clock itself is moving slower in the fast-moving reference frame it's that time itself moves slower. You don't notice your clock moving slower because you're moving slower too.

However, I might think that my clock is stationary and yours is moving past me, from your point of view your clock is stationary and mine is moving past you. As we've seen your point of view is equally valid and you will see time travelling slower in my spaceship than in yours.

If looked through the window of your spaceship I'd see you moving in slow motion, ageing slower and you would see the same were you to look through my window.

We've seen from our simple starting assumption that time is actually relative – how much time has passed depends on your reference frame. It is vital therefore when talking about time in relativity to specify which reference frame you measured the time in. The 'proper time' of an object is the time as measured by a clock which is in the same reference frame as that object. For example, the 'proper time' for me would be the time measured on a clock in the same spaceship as me (the t as opposed to the t' in the above calculation).

Homework

Research the Michelson Morley experiment. Give a brief description of the experimental setup (with the aid of a simple diagram) and describe in your own words what the experiment was attempting to observe. Explain why the experiment has been described as the most famous 'failed experiment' of all time. If possible, use your knowledge of special relativity to explain the result of the experiment and discuss whether in your opinion the experiment was, in fact, a failure.

Tutorial 3 – Special Relativity Calculations

What is the Purpose of Tutorial 3?

- Use the time dilation formula in calculations.
- Look into the experimental evidence for time dilation in special relativity.
- Understand the ‘twin paradox’.

Experimental Proof

So far we’ve started from the assumption that all the laws of physics remain the same in a constantly moving reference frame and we’ve come to the conclusion that this leads to weird things happening with time but is there any proof?

Yes. The first proof came from looking at muons. Muons are basically fat electrons. They have the same properties as the electron but are heavier. Unlike electrons they’re not stable and will decay very quickly (in $2\,x\,10^{-6}$ seconds). Muons are produced by ‘cosmic rays’. Cosmic rays are particles which are accelerated to really high energies as they are pulled towards earth due to the earth’s gravitational field. They then collide with particles in the earth’s upper atmosphere these collisions can lead to the creation of new particles.

Muons are generally produced at a height of about 10km above earth and since they have so much energy will travel very fast, in fact they travel at 0.9997 times the speed of light, c (where $c\ = 3\ \times 10^{8}$ m/s).

If we ignore the effects of time dilation how far will the muons travel before decaying?

According to this calculation would they reach the earth’s surface?

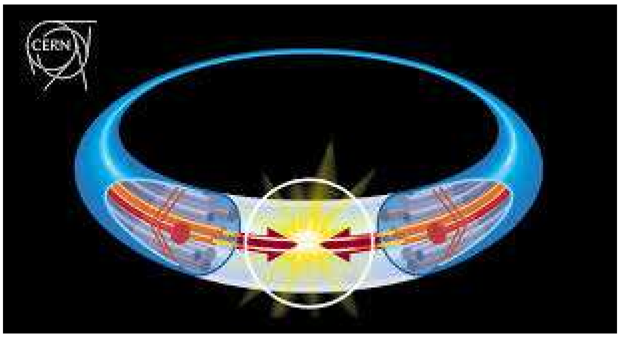
We should find that the muons will travel less than a 1km so should decay before reaching the earth's surface. However, because the muons are travelling so fast let's think about time dilation. The decay time of the muons will be the time taken for the muons to decay in their rest frame (their proper time, t). However, we as observers on earth aren't in the muon's rest frame.
Using the formula for time dilation calculate how much time will pass on earth (t') for the muons to decay.

Travelling at 0.9997c how far can the muons travel in this time, t'?

Will they reach the earth's surface?

In fact, muons originating from cosmic rays have been observed on the earth's surface. This is strong proof of time dilation as we can see from the calculations above.

Particle accelerators

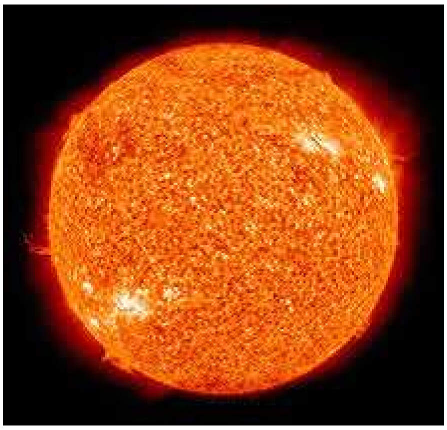


Particle accelerators use electromagnetic fields and magnets to accelerate charged particles to incredibly high speeds. Once accelerated to high speeds the particles collide and the products of the interactions which result from the collision are studied. Layers of detectors surround the collision point so that the fast-moving particles can be detected. Millions of pieces of data have been collected from these accelerators and all confirm Einstein's theory of relativity to perfect precision.

The Twin Paradox

Imagine two identical twins on earth. One builds herself a rocket and travels at high speed into space. Through her telescope she sees her twin still on earth ageing much more quickly than she is in her moving rocket. She then returns to earth in her rocket and finds, while she's still young her no longer identical twin has aged horribly. Since one twin is old and the other young how can this be consistent with our original postulate that it's impossible to tell which one was actually moving?

Thought Experiment: The Sun



The sun emits radiation equally in all directions (isotropic) in space so if we consider conservation of momentum the sun's velocity does not change as a result of emitting radiation (its kinetic energy doesn't change). However, the sun has definitely lost energy which is carried away with the radiation. Where has this energy come from? How can this be consistent with energy conservation?

Homework

Produce a short piece of writing describing time dilation and the evidence to support it. Include a description of the twin paradox in special relativity, and how it is resolved. You can use evidence we've discussed during the tutorial as well as any additional research you've conducted yourself.

Problem Set

1) The international space station moves at around 8 Km/s. If an astronaut travels on the international space station for one year, how much time would have passed for a stationary observer on earth.
2) If time dilation is a genuine affect why is it not observable on earth? Use a calculation to support your answer.
3) A muon is observed in a particle accelerator and exists for 4×10^{-5} seconds before decaying. At what speed was the muon travelling? Express your answer as a fraction of the speed of light.
4) Why are charged (as opposed to neutral) particles always used in particle accelerator collisions?
5) A particle has lifetime τ (in its own reference frame) and is travelling with speed v. Express the distance the particle travels before decaying in terms of τ and v. Hence calculate the speed of a particle with lifetime 10^{-9} seconds which travels a distance of 10^{-7}m before decaying.

Tutorial 4 – Discrete Symmetries in Physics

What is the Purpose of Tutorial 4?

- Understand what is meant by the discrete symmetries C, P and T.
- Understand what is meant by the combined symmetry CP
- Understand how particles are created and destroyed in pair production and annihilation and perform calculations relating energy and mass.
- Understand the idea of a broken symmetry and how CP violation relates to the matter anti-matter asymmetry in the universe.

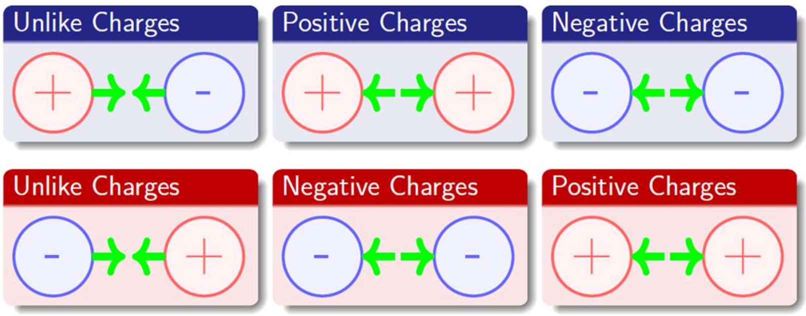
Fundamental Forces

- Gravity
- Electromagnetism (responsible for force between charged particles)
- Strong Force (responsible for sticking nucleus together)
- Weak Force (responsible for nuclear decay)

If a symmetry exists in the universe, it must exist in all four fundamental forces. The standard model of particle physics describes the final three forces. There is still no theory which can combine all four.

Charge Conjugation (C)

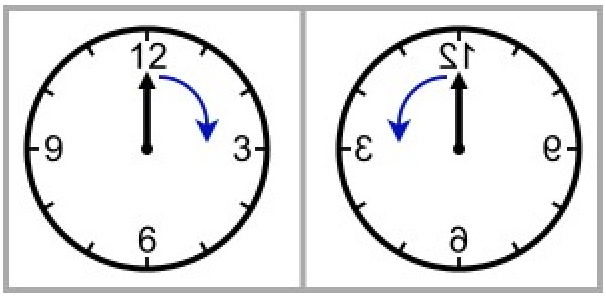
Charge conjugation (C) is the process of switching all particles into anti particles.



We saw in tutorial 1 that electromagnetism is symmetric under C.
Do you think a C transformation would affect gravity?

In fact, the strong force is also symmetric under C but the weak force isn't.

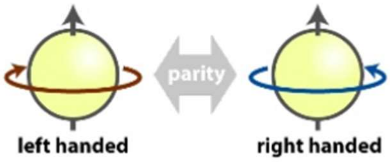
Parity Transformation (P)



Look at the image above which shows a parity transformation. Can you describe what has happened?
The left-hand image is a normal clock, where in day to day life might you see the right-hand image?

Is this a continuous or discrete transformation?

Do you think Parity transformation is a symmetry of the universe?



Parity transformation is significant in particle physics because particles actually have a 'handedness' (in the same way that each of our hands is either a left or right hand). We can visualise the handedness of a particle as the direction of rotation about a central axis. The parity transformation reverses the handedness of a particle (just as the mirror image of a left hand turns it into a right hand and vice versa).

In the weak interaction some decays only occur with particles which are left-handed and anti-particles which are right-handed. Therefore, parity isn't conserved in the weak interaction. (This also explains why C isn't conserved in weak interactions).

Time Reversal (T)

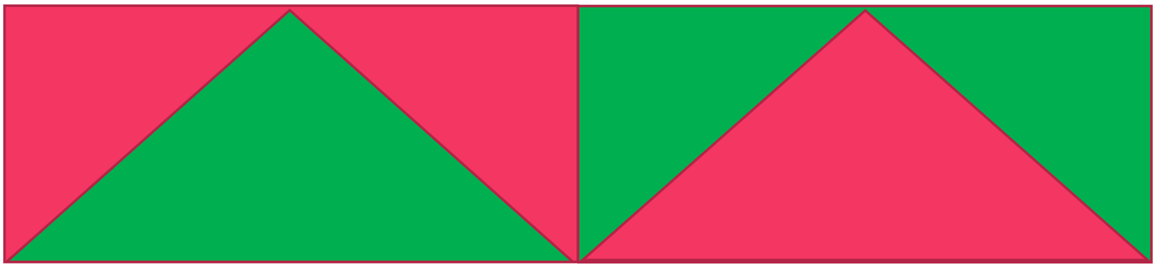
The Time-reversal transformation literally means reversing the direction of time. Will the universe look the same if run in reverse?

If I filmed myself throwing a ball in the air and catching it then showed you the video in reverse would you be able to tell?

Are there some processes which can only happen in one direction?
Do you think T is a symmetry of the universe?

Can this be directly experimentally verified?

Symmetry Combinations



Look at the above image. Imagine exchanging the colours green and pink. Is this a symmetry of the image?

What about reflecting the image across the central vertical line? Is this a symmetry of the image?

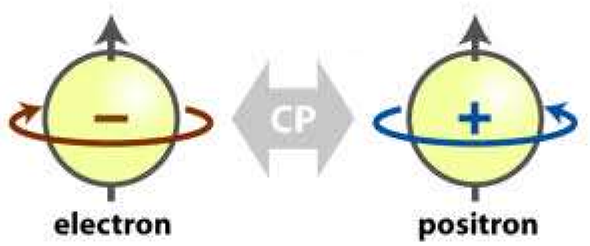
What about the combination of the two transformations?

Is there a difference between reflecting the picture down a central line and switching the pinks to green and green to pinks?

We have discussed that C, P and T as individual symmetries are not symmetries of the universe. What about combinations?

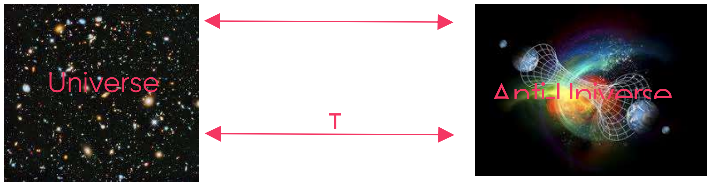
CPT and CP Symmetry

CPT can be proved to be an exact symmetry of nature, the exact reason why is beyond the scope of this course but as long as relativity holds (and so far, all experiments have shown that it does), then we can be sure CPT is a perfect symmetry.



CP (the combination of C and P only) was for a long time thought to be an exact symmetry. Since some weak force interactions only occur with left-handed particles and right-handed anti-particles if we perform the C and P transformation at the same time all these interactions still work. CP symmetry is important because it would mean that there was a symmetry between particles and anti-particles in the universe.
In fact, since CPT is an exact symmetry (i.e. if you perform the CP transformation then the T transformation you get back to exactly the same universe you started with) therefore performing the CP transformation (changing all particles into anti-particles is equivalent to performing the T transformation (reversing the direction of time). Can you explain why this is the case (look at the diagram below if helpful).

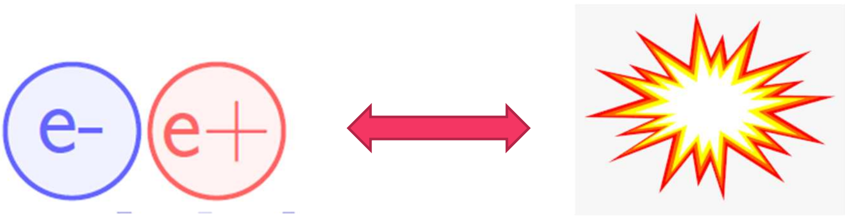
C



Since performing the CP transformation (which changes particles into anti-particles) is equivalent to the T transformation we can actually view anti-particles as particles which are travelling backwards in time!

Particles and Anti-Particles

What happens when you bring particles and anti-particles together?



This is called annihilation. A particle and an anti-particle 'annihilate' and turn into energy (in the form of Electromagnetic radiation). The process can also happen the other way in what's called 'pair production'. With enough energy a particle, anti-particle pair can be produced.

What about energy conservation? If we take a particle and an anti-particle with no kinetic energy and they annihilate each other giving out energy where did this energy come from?

The answer is one of the most famous physics equations of all time (and originally written down by Einstein, one of the most famous physicists of all time).

Energy and Mass

We've seen that we can create mass from energy and turn mass into energy but how much energy is involved?

The average house in the UK uses around 1×10^{9} joules of electrical energy, costing over £50, each month. A pound coin weighs 8.75g. If we could convert its mass into energy how long could an average family power their home off a single pound coin?

The early Universe and the origins of matter

We've established that mass can be created if we have large amounts of energy. If we want to establish where the mass in the universe came from, we need to consider a time in the universe's history where very large quantities of energy were available.

There is lots of evidence that the universe originated in an unimaginably hot, dense state.
What is the name of this theory?
Can you describe some of the most compelling evidence for this?

Matter, Anti-matter Asymmetry

$$\text{Energy} \rightarrow \text{Particle} + \text{Antiparticle.}$$

$$\text{Particle} + \text{Antiparticle} \rightarrow \text{Energy}$$

The existence of large amounts of energy in the early universe can explain how mass could be created, however we have a problem. Both pair production and annihilation are symmetric between particles and anti-particles. Every time we create a particle, we also create an anti-particle. Every time we destroy an anti-particle, we destroy a particle too.

What observation can we make about our universe which contradicts this symmetry?

For every anti-particle in the universe there are at least 10^{15} particles. The universe is very much not symmetric between particles and anti-particles – there must be some form of CP violation. This is a good thing – if there was an anti-particle for every particle they would constantly annihilate and leave us with an empty universe (lots of energy and no mass). It does however beg the question why the universe is so asymmetric. The standard model of particle physics goes some way towards explaining this (again within the weak force). However, the level of CP violation in the standard model is quite subtle and not enough to explain the huge discrepancy observed in the universe. The matter-anti-matter asymmetry problem is one of the great mysteries of modern physics!

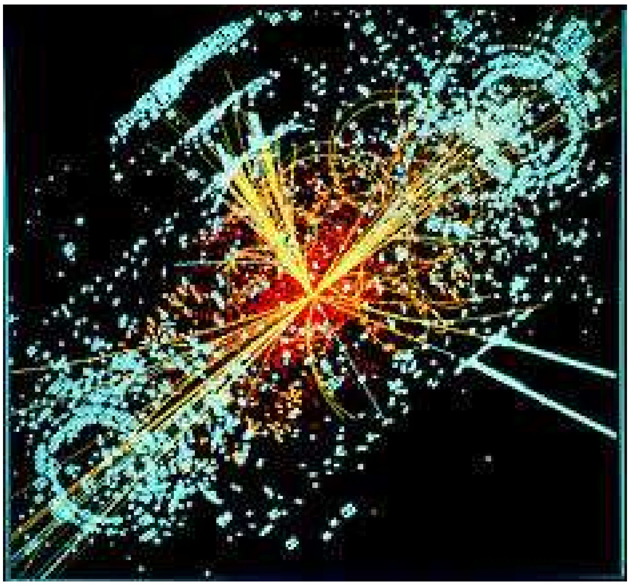
Homework

Produce a short piece of writing describing the discrete symmetries of C, P and T and what is meant by the combined symmetry CP. Research the evidence for CP violation and give a brief description of the matter anti-matter asymmetry problem.

Problem Set

1) A penny coin weighs 3.56g. How much energy could be released from the mass of this coin?
2) Energy consumption in London is around 4.5×10^9 Watts (Joules per second). If we could convert mass directly to energy with $100\ \%$ efficiency what mass would be required to power London for a week? Can you think of any reasons why this isn't a practical method of energy generation?
3) In a particle accelerator an electron collides with a positron to produce a muon and an anti-muon. How much energy must be given in total to the electron and positron in order to enable this interaction to take place? (You will need to do some research to establish some pieces of data before carrying out this calculation).
4) A proton and antiproton, initially at rest annihilate and the energy released creates a muon antimuon pair. What is the maximum kinetic energy of the muon produced in this interaction? (You will need to research some pieces of data to do this calculation).

Tutorial 5 – Overview of Symmetry



What is the Purpose of Tutorial 5?

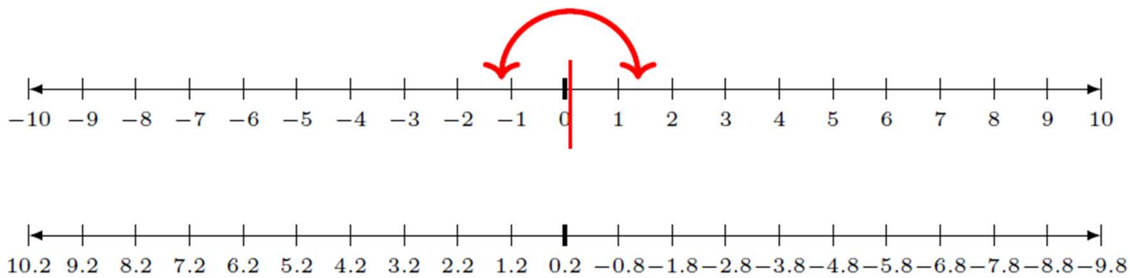
- Understand the concept of symmetry breaking and look into the mechanisms by which it can occur.
- Review what we mean by symmetry, and the specific examples we've covered (Lorentz invariance, CPT symmetry).

Symmetry Breaking

We have seen that sometimes symmetries are 'broken', meaning a symmetry is not exact or a symmetry we expect to see in the universe is not, in fact observed. In the case of CP symmetry, it is necessary for the symmetry to be broken in order to explain the massive matter anti-matter asymmetry in the universe.

Direct Symmetry Breaking

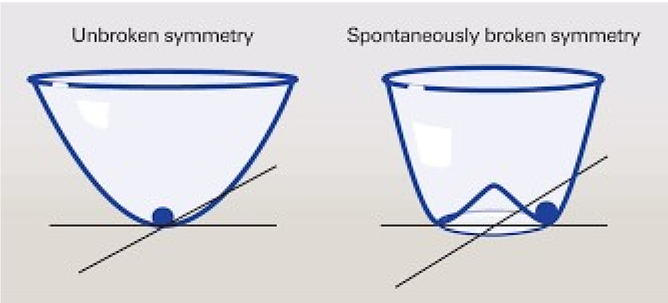
One way a symmetry (such as CP) can be broken is simply by having a theory in which the symmetry is almost exact. It looks at first glance to be a perfect symmetry but on closer inspection is only an approximate symmetry of the system.



In the first tutorial we saw that addition was symmetric under a reflection in the number line around 0. In the above diagram instead of reflecting the number line around 0 it has been reflected around 0.1. Now we can see that this will break the symmetry (for example $-1 + 3 = 2$ becomes $1.2 + -2.8 = -1.8$ which is no longer a valid sum). However, if we rounded each of the numbers to the nearest significant figure the symmetry would still be valid. The breaking of the symmetry is only apparent when we look more closely, or in terms of physics, make more precise measurements.

This type of symmetry breaking has been observed for CP violation when we study particle decays with extremely high precision in particle accelerators, however, as we can see in the above example it only provides small levels of symmetry breaking. This type of CP violation isn't sufficient to explain the level of matter-anti matter asymmetry we see in the universe.

Spontaneous Symmetry Breaking



Another method of symmetry breaking is known as 'spontaneous symmetry breaking'. Look at the diagram of a ball in a glass bowl. In the diagram on the left the picture is entirely symmetric with the ball in the centre of the bowl. Look at the right-hand picture. Before introducing the ball to the bowl it will be entirely symmetric, if we then place the ball exactly in the centre of the bowl, initially, it will be entirely symmetric however with even a tiny fluctuation of its position the ball will fall at random to one side of the bowl, breaking the symmetry of the system (even though the bowl itself and the ball's starting position were entirely symmetric).

This is how some symmetries are thought to be broken in the universe. Despite the universe obeying certain symmetries, random fluctuations can lead the universe into a state which is no longer at all symmetric.

Symmetry Review

What is symmetry?

A symmetry is a feature of a system which is unchanged under a certain transformation.

Important symmetries in Physics

Symmetry Name	Continuous or discrete?	Symmetry of the Universe?	Consequence for the Universe.
Translation in Space	Continuous	Yes	Conservation of Momentum
Rotation in Space			
Translation in Time			
Charge Conjugation (C)			
Parity Transformation (P)			
Time Reversal (T)			
CP Symmetry			
CPT symmetry			
Velocity Boost (Lorentz Symmetry)			

Special Relativity

What is the equation for time dilation?

What do each of the terms in this equation mean?

What is the 'proper time'?

Einstein's Equation

How is energy related to mass?

By what process can energy be transferred to mass?

By what process can mass be transferred into energy?

Homework: Draft your final assignment and attempt the problem set as detailed below.

Symmetry and symmetry breaking have been central to modern physics over the last 150 years and continues to play a pivotal role on the road to probing key unsolved problems at the heart of our understanding of the universe. Produce a 1000-word essay detailing to what extent you agree with this statement.

Problem Set

1) Consider the transformation $x \rightarrow \frac{1}{x}$ (the transformation on numbers where each number is transformed into its reciprocal e.g. $2 \rightarrow \frac{1}{2}$, $\frac{2}{3} \rightarrow \frac{3}{2}$ etc). Which number(s) if any would be unchanged by this transformation? Would you describe this as a continuous or discrete transformation? Is this transformation symmetric under addition? Is it symmetric under multiplication? (You can use examples or better still algebraic proof to justify your answer).
2) A spaceship travels past you at half the speed of light. When a year has passed on your spaceship how much time will you observe having passed on the moving spaceship?
3) A π^0 particle has a lifetime of 3×10^{-17} seconds. A physicist is attempting to observe the particle before it decays. The particle detector he is using has a spatial resolution of 2×10^{-6}m. (This means the detector cannot observe any particle which travels less than this distance before decaying). What is the minimum speed the particle must travel in order to be detectable?
4) A particle is observed moving at 99% of the speed of light. It travels 0.1m before decaying. What is its lifetime (in its own reference frame)?
5) Assuming that CPT is an exact symmetry of nature explain why a violation of CP symmetry implies a violation of T symmetry.
6) The τ particle (a particle similar to the electron and muon but thousands of times heavier) has a mass of 3×10^{-29}Kg. If this particle annihilates with its antiparticle how much energy will be released?
7) During the 'main sequence' phase of a star's lifetime the energy released by the star is due to the nuclear fusion of four hydrogen nuclei into a helium nucleus. The mass of the hydrogen nucleus is 1.67×10^{-27}Kg and the mass of a helium nucleus is 6.64×10^{-27}Kg. The power output of the sun is 3.85×10^{26}Watts (joules per second). Initially the sun had a mass of around 2×10^{30}Kg and was composed mainly of hydrogen. Use this information to produce an estimate for how long the main sequence of the sun will last.

When writing your essay, you should be careful to introduce the topic and define the terms you use (for example symmetry, discrete, continuous etc). When discussing various symmetries, you should explain how they came to be discovered and distinguish between a symmetry which is assumed to be true, has been proved theoretically to hold or has been experimentally verified. You should also discuss which particular aspects of symmetry and symmetry breaking are important in our current search for 'new physics'. It is important to reference the source of your information and if you are quoting a source directly you should use quotation marks to make this clear. Your essay should be understandable to an intelligent reader who is unfamiliar with the topic.

When attempting the problem set questions you should first establish what basic principle is involved. Write down any equation which you think will be relevant and clearly state the information you have available (which variables in your equation are known and which are unknown?). If you can't see how you're going to calculate the final answer, consider what you could calculate which might be a useful intermediate result. You can also start from the answer you want and work backwards. What intermediate result might be useful in helping you get to the final answer? By working forward from the information you have and backwards from the information you want you might be able to meet in the middle.

Be careful with units. It's always safer to first convert everything into SI units (m, Kg, s, J). This will give you an answer in SI units which you can then convert into a more convenient unit at the end of the question (for example if you're talking about the lifetime of a star is it more sensible to talk about seconds or years?). Be careful when you consider reference frames. Which is the proper time, and which is the 'dilated' time?

Remember that marks are awarded for partial solutions so make sure you carefully show your working.

Essay writing reflection

Use the checklist below to reflect on your essay writing ability at the moment. Read the statements for each skill and then tick the box that most closely fits how you currently feel about your ability to do that skill.
You will use this to help your PhD tutor give you feedback in your next tutorial. They will give you specific advice on how to improve these areas in relation to your draft assignment so be completely honest.

Addressing the question

I can…

- identify what the title or question is asking me to do
- select relevant information from the course to answer the title or question
- explain why the information I have used is relevant

I feel…

Confident	Partially confident	Not confident
☐	☐	☐

Using evidence

I can…

- select evidence that supports my points
- link evidence to my points and ideas
- clearly and convincingly explain how my evidence supports my points
- use references

I feel…

Confident	Partially confident	Not confident
☐	☐	☐

Developing an argument

I can…

- include a point of view or position in response to the title or question
- develop and explain my point of view
- argue why my point of view or position is correct

I feel…

Confident	Partially confident	Not confident
☐	☐	☐

Critical evaluation

I can…

- ensure I analyse events and information rather than just describe them
- assess the relevance and significance of the ideas and examples I am writing about

I feel…

Confident	Partially confident	Not confident
☐	☐	☐

Structuring

I can…

- arrange my points in to a logical order
- write paragraphs that focus on one idea or point each
- write an introduction that explains how I will deal with the issues of the essay
- write a conclusion that sums up my main points

I feel…

Confident	Partially confident	Not confident
☐	☐	☐

Use of language

I can…

- minimise spelling, punctuation and grammar errors
- ensure my writing makes the meaning clear and easy to follow
- write using and appropriate tone and level of formality

I feel…

Confident	Partially confident	Not confident
☐	☐	☐

Tutorial 6 – Draft assignment feedback and reflection

What is the Purpose of Tutorial 6?

- To received feedback on your draft assignment
- To reflect on your essay writing skills
- To identify practical ways to improve your assignment

What three things can you now do to improve your assignment and your essay writing ability?

1

2

3

Tutorial 7 – Final assignment feedback and reflection

What is the Purpose of Tutorial 7?

- To receive feedback on final assignments.
- To write targets for improvement in school lessons.
- To reflect on the programme including what was enjoyed and what was challenging.

Final assignment feedback

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

My target for future work is…

Reflecting on The Scholars Programme

What did you most enjoy about The Scholars Programme?
•   •   •

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

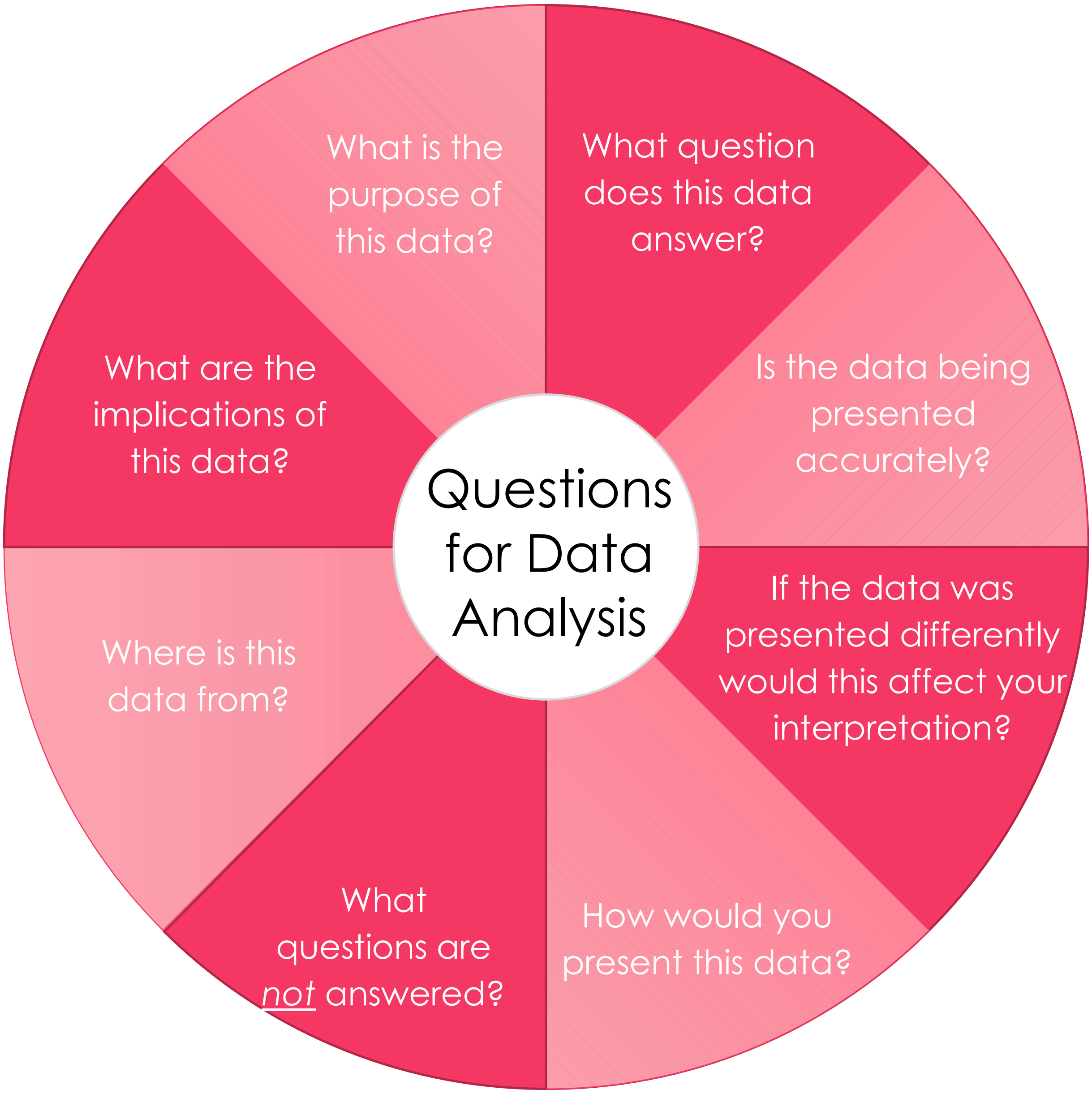
Appendix 1 – Finding and Evaluating Good Academic Sources

There are so many places to get information that it is important to decide if something will be a good **academic** source for your homework or final assignment. When assessing a source, you don't have to read the whole thing to decide if you may want to use it. Instead read the first paragraph or so and use the checklist below to help you decide it this is a good academic source.

		Questions to Ask
Authority	☐	Who is the author? (this could also be an organisation, rather than a single person)
	☐	Check their credentials: what knowledge or skills do they have that lets you confirm they know what they're talking about?
Reliability	☐	Does the information appear correct?
	☐	Does the author tell you where they got their information from?
	☐	Has the information been reviewed or checked by others?
Relevance	☐	Does the source talk about the topic clearly and effective?
	☐	It is up-to-date? If not, is there a good reason to use an older source?
	☐	Does it provide new and useful information for you?
Objectivity	☐	Does the author explore or acknowledge multiple points of view?
	☐	Are they stating mostly facts? Evidence? Opinion? – Remember opinion is fine, as long as it is supported by reliable evidence.
	☐	Does the headline or text try to make you scared or angry about the topic? If so, it might not be the best **academic** source.
Writing Style	☐	Is the source well organised? (Or is it difficult to follow the author's point?)
	☐	Does the text sound academic? (Or is it informal or chatty?)
	☐	Are the author's points backed up by evidence and do they let you know where that evidence came from?

If you're not sure if something would be a good academic source, **send your tutor a message on the VLE** and they can help you evaluate the source together.

Appendix 2 - Data Analysis Tool – Investigating how data is represented



Appendix 3 - Referencing and Plagiarism

You may well have heard of plagiarism before, and to have heard that it is something that you need to avoid.

Plagiarism is seeking to pass off the work of others as your own and is considered a form of cheating. Universities take a very strict line on **plagiarism** which can sometimes even result in being removed from a course.

How do you avoid **plagiarism**? There are two essential parts to this:

1. Understanding what needs to be referenced
2. Referencing your sources clearly and 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.

Needs to be referenced	Does not need to be referenced
• Direct quotations e.g. 'A diet low in fruit and vegetables is 'among the top mortality risk factors all over the world' • Paraphrased material e.g. For both men and women, adopting a vegetarian diet can significantly reduce the risk of premature death. • Facts, figures or statistics e.g. Healthy diet, exercise and being a non-smoker can increase life expectancy by 9 – 15 years.	• Facts already common knowledge e.g. A vegetarian diet is one that excludes meat.

What would a good reference look like?
Text: The proponents of vegetarian, vegan or largely plant-based diets argue that, coupled with regular exercise and being a non-smoker, these diets can increase life expectancy – some studies suggest by up to 15 years [1].

Endnote: [1] Salonen, Arto O. & Helne, Tuula, T., 'Vegetarian Diets: A Way towards a Sustainable Society', *Journal of Sustainable Development* 5:6 (2012), pp. 10-24, (p. 11).

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.

The example here shows how we would recommend you reference in your Final Assignment.

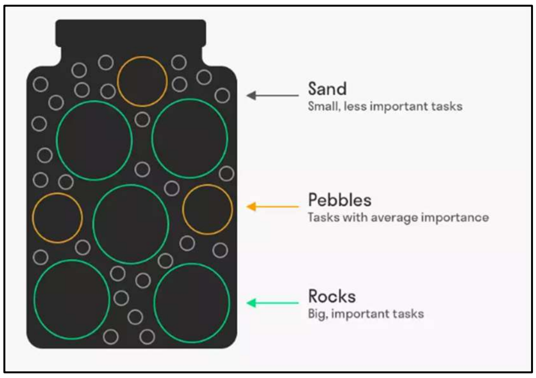
If you're not sure if something you have used in your essay needs to be referenced, **send your tutor a message on the VLE** and they can help you decide if it needs citation and write a reference. But as a general rule, **if in doubt, reference.**

Appendix 4 - Planning Effectively and Time Management

There are lots of things we want to do, need to do and would like to have time for. How do we **manage our time** so that we get all the essentials done, and even have time for some extras? We have some techniques you can try.

'Pickle Jar' Theory

If you have to fit stones of different sizes into a jar, they won't fit if you put the sand in first. But if you put the **rocks** in then the **pebbles** *then* the **sand**, there's enough room.



This theory suggests you should apply the same logic to your time: put in the **essential** tasks first, then the **important** tasks, then **everything else**.

Of course, you have to decide for yourself what is '**essential**'!

Backwards Planning

1. Work backwards from your deadlines
2. Put the **essentials** in first
3. Estimate how long tasks will take to make sure you start them in good time

Plan your week

Use the grid below to 'backwards plan' your week, putting in the **essentials** first, then the **important** tasks, then any **less important** things you'd also like to get done.

Monday	Tuesday	Wednesday	Thursday	Friday

Appendix 5 - Writing an Effective Essay

		Where should I do this?	Have I done this?
R	Restate the Question	In my introduction	
A	Answer the Question	In my introduction	
G	Give evidence from other sources	To support any points I make in my paragraphs	
E	Explain how your evidence proves your point	Each time I give evidence	

Easy Essay Writing Wins

- Prepare an outline or mind map your ideas
- Make sure your essay has a clear structure
- Analyse don't describe! Description is great to introduce a topic, but make sure your essay also includes your argument and interpretation of the evidence you use
- Remember to PEEL (Point, Evidence, Explain, Link) and RAGE
    - Use relevant evidence and research to support your points
    - Link it back to the question and explain why your point answers the question
- Look at the mark scheme in your handbook or ask your tutor for help if you're not sure what to write.

Notes

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