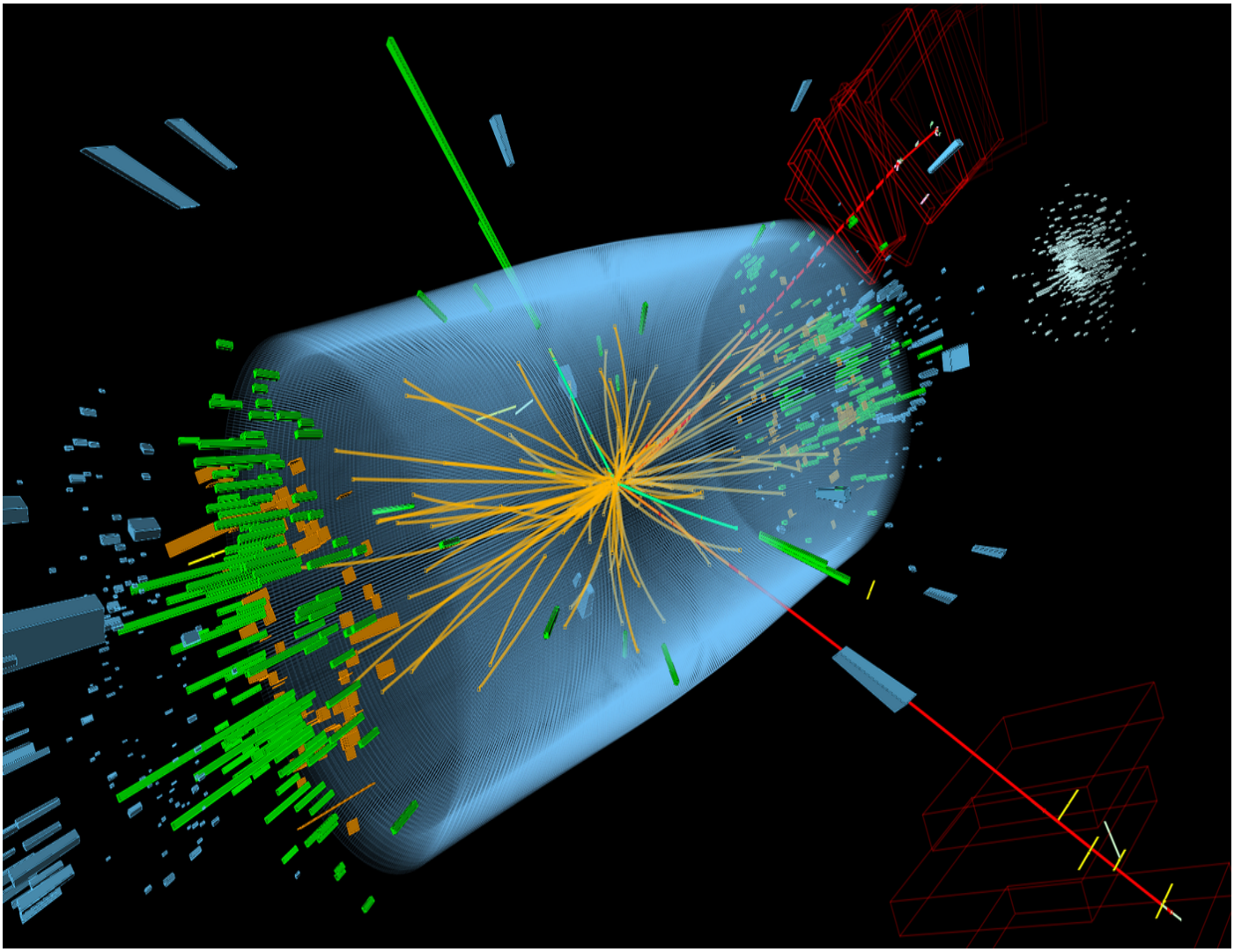

# What is matter made of?

*Key Stage 4 Programme – 2016-2017*

**Teacher Name** Daniel Robles Llana

**Pupil Name**_____

## Timetable and Assignment Submission

Fill this in with your teacher.

### Timetable – Tutorials

| Tutorial | Date | Time | Location |
|---|---|---|---|
| Atomic structure | | | |
| The Standard Model of Particle Physics | | | |
| The Fundamental Interactions | | | |
| The Particle Accelerator at CERN | | | |
| From the Big Bang to today | | | |

### Timetable – Homework Assignments

| Homework Assignment | Description | Due Date |
|---|---|---|
| Tutorial 1 | Atomic Structure | |
| Tutorial 2 | The Standard Model of Particle Physics | |
| Tutorial 3 | The Fundamental Interactions | |
| Tutorial 4 | The Particle Accelerator at CERN | |
| Tutorial 5 | From the Big Bang to today | |

### 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 |

| 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**<br><br>*Enter feedback here* | **How you could improve in the future**<br><br>*Enter feedback here* |
| **Learning Feedback Comment 2 – *Enter Key Learning Priority Here*** | |
| **What you did in relation to this Key Learning Priority**<br><br>*Enter feedback here* | **How you could improve in the future**<br><br>*Enter feedback here* |

| Learning Feedback Comment 3 – *Enter Key Learning Priority Here* | |
|---|---|
| **What you did in relation to this Key Learning Priority**<br><br>*Enter feedback here* | **How you could improve in the future**<br><br>*Enter feedback here* |
| **Resilience Comment** | |
| **How you showed learning resilience during the course**<br><br>*Enter feedback here* | **How you could build learning resilience in the future**<br><br>*Enter feedback here* |

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## Course Rationale

Have you ever wondered what the stars and the Earth are made of? What would you see if you looked inside matter with the most powerful of microscopes? What is the History of the Universe? What are the fundamental forces that hold together everything we see together? These are the questions particle physicist ask themselves every day in their research.

Particle physics is about being curious about the world around us and our place in it. It is about finding out what makes things up: how very big things are made up of smaller and smaller things, and in this way figure out how Nature and the Universe are organised.

In this course we will take you through the different pieces that particle physicists think make up the matter we see around us. We will start with something that you are probably familiar with from school: atoms, and what atoms themselves are made of: protons, neutrons and electrons.

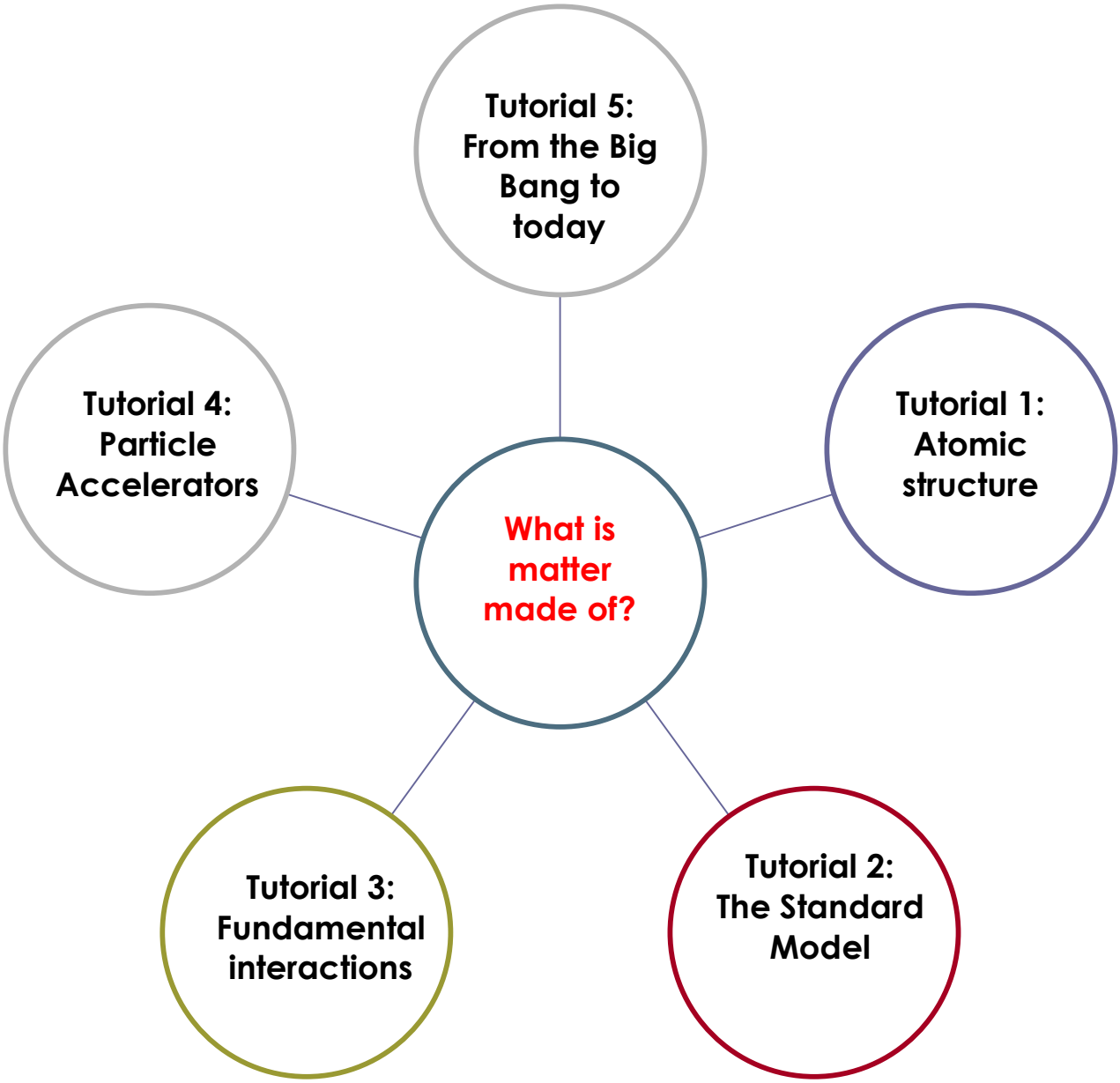
After that, we will go on a journey that will take us to what protons and neutrons are themselves made of. We will learn, for example, what quarks and leptons are, and we will understand how they fit into the Standard Model of particle physics.

We will then study the forces that hold quarks and leptons together, much like the force of gravity that we all know about keeps the moon turning around the Earth. These are called the Fundamental Interactions of Nature.

After that, we will understand how particle physicists managed to figure out the existence of quarks and leptons, and the Fundamental Interactions of Nature. We will study what particle accelerators are, how they work and what they are useful for.

Finally, we will use that knowledge to see how all the different pieces came together in the history of the Universe since the Big Bang to today.

## Course Map


Tutorial 5: From the Big Bang to today
Tutorial 4: Particle Accelerators
Tutorial 1: Atomic structure
What is matter made of?
Tutorial 3: Fundamental interactions
Tutorial 2: The Standard Model

## Mark Scheme

| Key Skill | 1st | 2.2 |
|---|---|---|
| **Understanding of key scientific concepts** | An appropriate range of key scientific concepts are understood and explained clearly and rigorously, using appropriate scientific terminology. Written answers are written in a logical, organised and structured manner. The student has undertaken independent research to link the key scientific concepts covered in the tutorials to a wider set of scientific concepts. | Key concepts are known and described accurately, but no extra independent research beyond the contents of the tutorial has been undertaken. Scientific terms, and conceptual relationships, might be confused at times. At times written answers might be lack a coherent conceptual structure. |
| **Qualitative scientific reasoning** | Ability to discuss in a logical and organised manner about the relationships between different scientific concepts, and to draw conclusions based on these relationships. Justification for any conclusions reached, with suitable exceptions described and reasoned. | Good assimilation of the course materials as explained in tutorials but limited exploratory scientific questions that extend the subject beyond the written tutorial material. |
| **Initiative and independence** | Independent thinking beyond the given tutorial materials. Make links to subjects not covered in the tutorials. Research of independent sources, capacity to judge the relevance of these sources and synthesize effectively their content in order to make connection with the materials covered in the tutorials. | Ability to interpret basic results. No attempt to provide a wider theoretical understanding of alternate interpretation of results. Occasional inclusion of irrelevant references. Confident in using concepts from current key stage but struggles with new concepts. |
| **Quantitative skills and intercurricular competences** | Numerical calculations are based on clear and rigorous conceptual understanding. All steps in a calculation are well laid out and justified. Results and estimations are always numerically accurate. | Numerical calculations are not always based on sound conceptual explanations. Not every step in a calculation is laid out clearly, although the final result might be accurate. Estimations might be confused at times. |

## Glossary of Keywords

| Word | Definition | In a sentence… |
|---|---|---|
| **Atom** | The smallest constituent unit of ordinary matter that has the properties of a chemical element | Hydrogen and Helium atoms are the two lightest atoms |
| **Elementary particle** | A particle that cannot be decomposed into smaller particles | Electrons, quarks, and photons are examples of elementary particles |
| **Quark** | Elementary particle inside a nucleon or a hadron | Quark come in six varieties: up, down, strange, charm, bottom, top |
| **Fermion** | A particle making up matter | Quarks and electrons are examples of fermions |
| **Boson** | Elementary particle mediating fundamental interactions | The photon is the boson that mediates electromagnetic interaction |
| **Electric charge** | Physical property of matter that causes it to experience the electromagnetic force | Particles can have positive, negative, or no electric charge at all |
| **Colour** | Physical property of quarks that causes them to experience the strong interaction | Colour is the equivalent of electric charge for the strong interaction |
| **Fundamental interaction** | One of the basic forces through which matter interacts with itself | There are four known fundamental interactions: gravity, electromagnetism, the strong and the weak interactions |
| **CERN** | Conseil Européen pour la Recherche Nucléaire (European council for nuclear research) | The world's largest particle physics laboratory and particle accelerator located in Geneva (Switzerland) |
| **Exponential notation** | A mathematical notation to write very large or very small numbers, as the numbers that typically appear in particle physics | For example, the speed of light is $3x10^8$ m.s$^{-1}$ and the radius of an atom is $10^{-10}$ m |
| **Mass-energy equivalence** | A formula discovered by Einstein relating the mass of a particle and the maximal total energy it can release | $E=mc^2$ |
| **Particle accelerator** | A machine that accelerates particles to nearly the speed of light and makes them collide and break up into new elementary particles | The Large Hadron Collider at CERN is the world's largest particle accelerator |
| **The Big Bang** | The primitive explosion or singularity from which the Universe was created | The Big Bang is the best established scientific model for how the Universe started |
| **Cosmic Microwave Background Radiation** | The thermal radiation or signal left over from the time of the Big Bang | By observing the Cosmic Microwave Background Radiation we can understand the physical conditions of the Universe at the time of the Big Bang |
| **LHC** | Large Hadron Collider | The world's largest accelerator, where the Higgs particle was discovered |

# Tutorial 1 – Atomic Structure

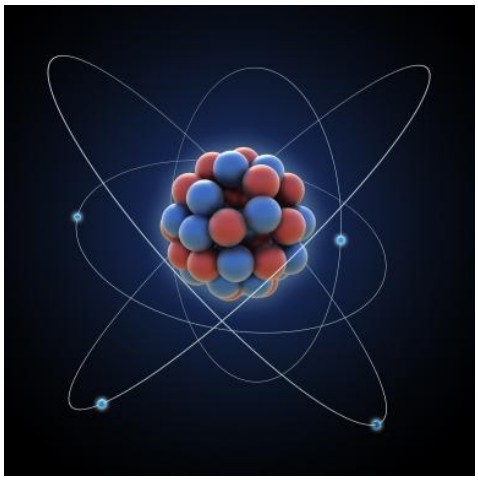


**Figure 1: The structure of an atom.**

## Today's Key Questions:

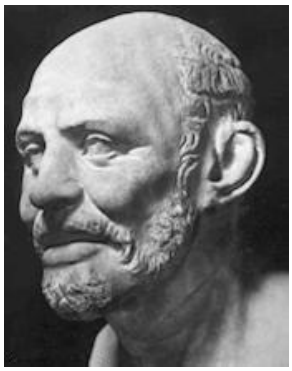
- Why study elementary particles?
- What is an atom?
- What are the different parts of an atom?
- How small are atoms?
- What makes atoms different?

## What is the Purpose of Tutorial 1?

- Get yourself familiarised with the idea of atoms.
- Get to know the different parts of an atom.
- Be able to tell the difference between these parts.
- Learn how different atoms make up matter.

## Why study elementary particles: the history of atoms

Atoms were long thought to be the smallest pieces of matter. They were first discussed by the Greek philosophers Leucippus and Democritus more tan 2000 years ago. For Leucippus and Democritus, atoms were the tiniest parts of matter that could be not be further subdivided ("atom" means indivisible in Greek).



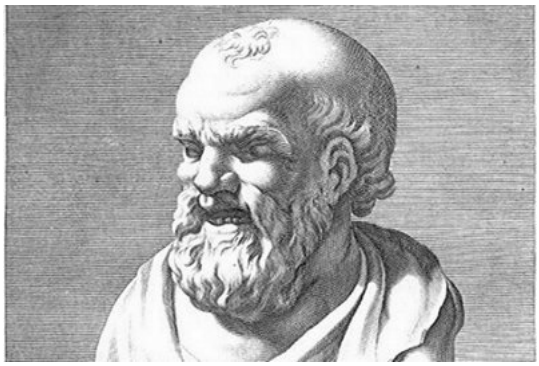


**Figure 2: The Greek philosophers Leucippus (left) and Democritus (right)**

The idea of atoms was confirmed in the 20th century with the works of Dalton, Rutherford, Bohr and others, who paved the way for the modern theoretical models used by physicists and chemists today.
Although we now know that atoms themselves are made up of more elementary particles, it is good to recall some key facts about atoms and their different parts, and how they are used to build up matter.

## Atoms and molecules

Matter organises itself into many different kinds of molecules, which are in turn made up of different kinds of atoms. However, while molecules can be very complex, and there are millions and millions of different kinds of molecules, atoms, on the other hand, have all a relatively simple structure, and there are only about 117 different types of known atoms. These atoms are called elements and appear in the periodic table. Most of them are found naturally, and some other have been created by man in the laboratory.

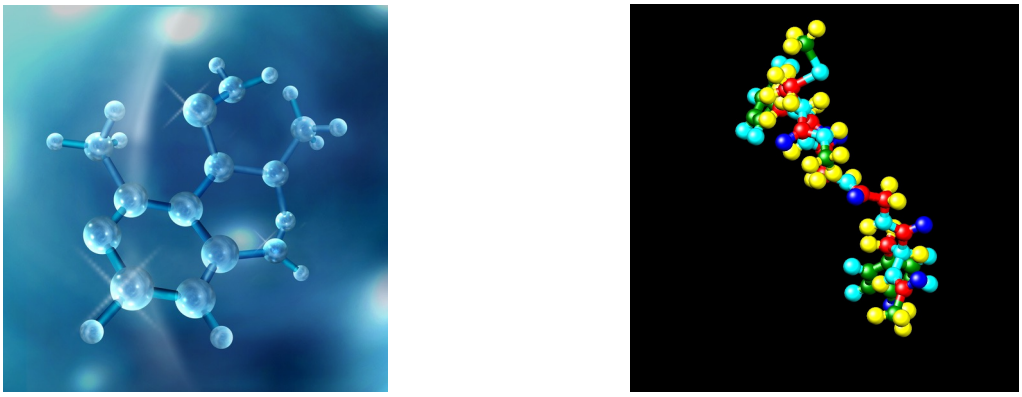


**Figure 3: Atoms arrange themselves and combine to form molecules.**

## Activity 1 – Atoms and molecules

Work in pairs and think about the following questions:

- You are given 3 Carbon atoms, 3 Nitrogen atoms, 10 Hydrogen atoms, 10 Fluorine atoms. How many molecules can you build with these atoms? (You can recall how many electrons these atoms need to complete their outer shells).
- Using your thoughts from the previous question, why do you think there are there many so more types of different molecules than types of atoms?

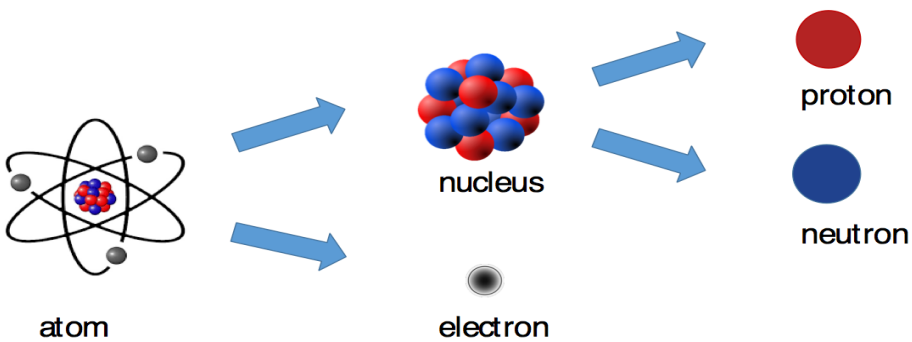



**Figure 4: Atoms are made of protons, neutrons and electrons**

## The structure of atoms

While atoms are used as building blocks for molecules, atoms are themselves built of smaller particles called protons, neutrons and electrons. Protons and neutrons make up atomic nucleus, and electrons occupy electronic shells that determine the chemical properties of atoms. Atoms are electrically neutral, and differ from each other in the number of protons (and neutrons) they have.

## Activity 2 – The structure of atoms

Work in pairs and think about the following questions:

- You are given 15 protons, 15 neutrons, and 15 electrons. How many different types of atoms can you build?

- Using your thoughts and results from the previous question, why do you think physicists consider protons, neutrons and electrons to be more fundamental particles than atoms?

## The forces inside atoms

Protons, neutrons and electrons are very different particles, not only when one looks at their masses but also when one looks at their electromagnetic properties. Protons have positive electric charge, neutrons have no electric charge, and electrons have negative electric charge. Since protons and electrons have opposite electric charges, they attract each other. This attraction is responsible for atomic stability.

## Activity 3 – A simple mathematical model of the atom

Electrons are held in stable circular orbits around the nucleus because centripetal forces (forces that push electrons away from the nucleus) are balanced by electrostatic attraction.

The centripetal force acting on an electron with speed v at distance r from the nucleus is

$$\frac{m_e v^2}{r}$$

The electrostatic attraction between an electron and a nucleus of charge Z is

$$\frac{Z k_e e^2}{r^2}$$

These two forces should be balanced for a stable atom. From this condition, derive:

- The electron's speed at any radius.
- The electron's total energy at any radius.

## Homework 1: Atomic parts and orders of magnitude

- In your own words, describe why you think exploring the basic components of matter is important? [20 marks]

- What is the typical size of an atom? [20 marks]
  If you lined up hydrogen atoms side to side along 1cm, how many atoms would you need?

- How big is the diameter of a proton? [20 marks]

What is the mass of a proton in Kg?
How many protons would you need to balance 1g of sand?

- How big is the diameter of an electron? [20 marks]
  What is the mass of an electron in Kg?
  How heavy is the electron relative to the proton?

- Estimate how many atoms you can fit in a cubic centimetre of matter. [10 marks]

- Make an estimate of how many atoms the human body contains. What about the Sun? [10 marks]

# Tutorial 2 – The Standard Model of Particle Physics

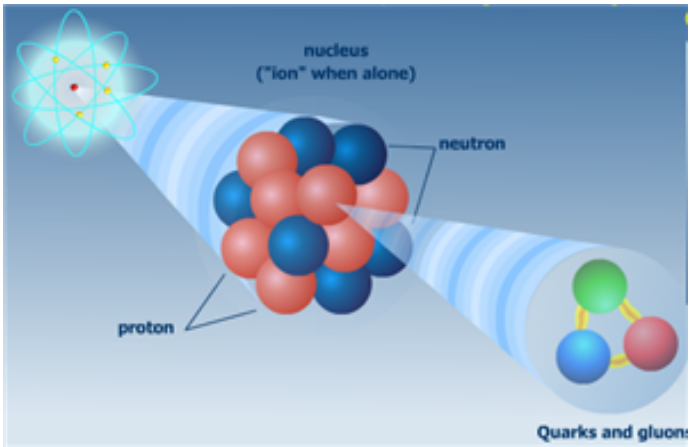



**Figure 5: The components of protons and neutrons**

## Today's Key Questions:

- Why atomic nuclei don't fall apart?
- What is the strong force?
- What is inside protons and neutrons?
- What are quarks and leptons?

## What is the Purpose of Tutorial 2?

- Understand the stability of atomic nuclei.
- Understand what quarks and leptons are.
- Understand how the strong force inside the nucleus works.

## The strong force inside atomic nuclei

You have seen in the previous tutorial that atomic nuclei are made of protons and neutrons. Protons have positive electric charge and neutrons have no electric charge.

Now we ask the following question: if particles with same charge repel each other, how is it possible that repulsion between protons doesn't make atomic nuclei fall apart? The reason for this is that protons and neutrons, though very small, are not elementary particles themselves. In fact, protons and neutrons are made of more elementary particles called quarks. In addition to electric charge, quarks have a different kind of "charge" called colour. Because quarks have colour, they experience a new force called the strong interaction. This interaction is very strong and attractive, and holds atomic nuclei together.

## Activity 1 – Comparing the electromagnetic and the strong forces

In this activity we are going to compare the strengths of the electric and the strong interaction inside atomic nuclei.

Working in pairs:

- Knowing that the radius of a proton is about $0.88 \times 10^{-15}$ m, estimate the radius of an atomic nucleus with atomic number Z.
- Use your estimation to calculate the electromagnetic force between two protons inside the atomic nucleus with atomic number Z using the formula

$$F_{el} = \frac{Zk_e e^2}{r^2}$$

- Compare what you just found with the strong interaction between the same two protons inside the atomic nucleus, using the formula for the strong interaction

- How much stronger is the strong interaction than the electric interaction inside atomic nuclei?

## Quarks and leptons

Protons and neutrons, on the one hand, and electron on the other, are very different types of particles. You can suspect this already because their masses are so different. In fact, they belong to two completely different families of particles.

These big families of elementary particles are called quarks and leptons. Particles made of quarks are called baryons (if they are made up of three quarks), or mesons (if they are made up of two quarks). Both protons are neutrons are made up of three quarks, and are therefore baryons. Electrons, on the other hand, are not made up of quarks. They belong to the big family of leptons. Together, quarks and leptons are known as fermions, and they form all matter that we see around us.

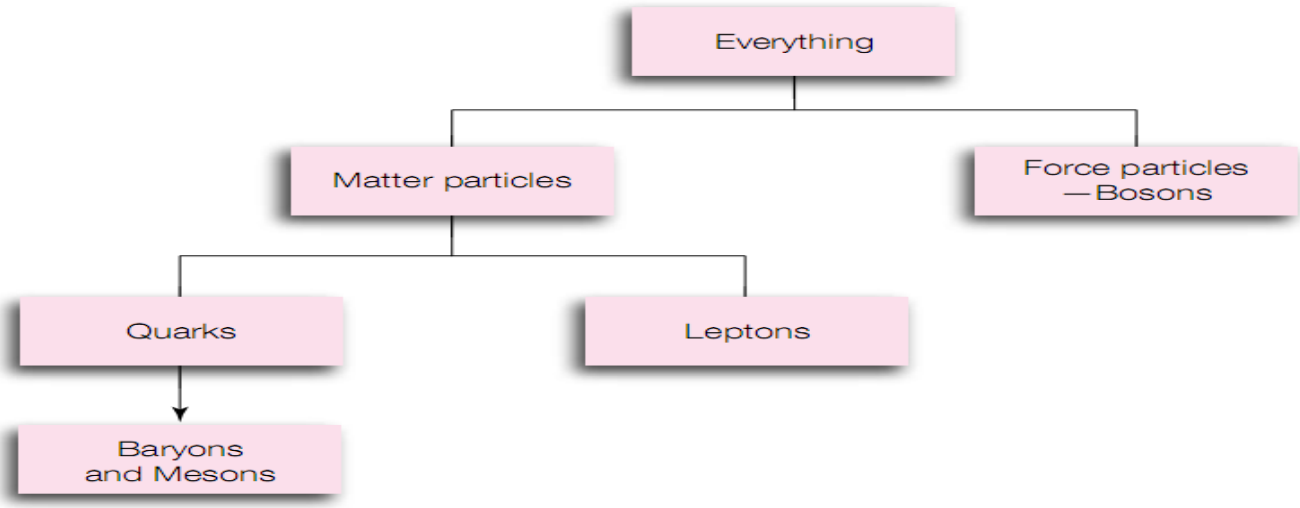



**Figure 6: The organization of matter and interactions**

However, we know there are more different types of quarks and leptons than those found in atoms.
In fact, the quarks found in ordinary atoms are just called "first generation" quarks. Quarks can come in two other generations. Similarly, leptons can come in two other generations apart from electrons. The structure can be summarized in a table, much like the Periodic Table of the Elements. This classification is called the standard model of particle physics.

## Activity 2 – Brainstorming activity: The Standard Model and the periodic table

Working in a group, think of:

- Three similarities between the Standard Model of particle physics and Mendeleev's periodic table.
- Three differences between the Standard Model of particle physics and Mendeleev's periodic table.

## The mass and energy equation

Einstein discovered a very famous equation relating the mass of a particle, and the so-called rest energy it contains. The equation is

$$E = mc^2$$

where c is the speed of light

$$c = 300\,000\,000\ m \times s^{-1}$$

To convert rest energies to masses, you can use the inverse equation

$$m = \frac{E}{c^2}$$

## Activity 3 – The mass and energy equation and Standard Model particles

Using this equation, and using 1 J = 6.242 x $10^{12}$ MeV, compute the mass is Kg of the Up, Strange, and Top quarks. How do they compare to the mass of the proton and the neutron?

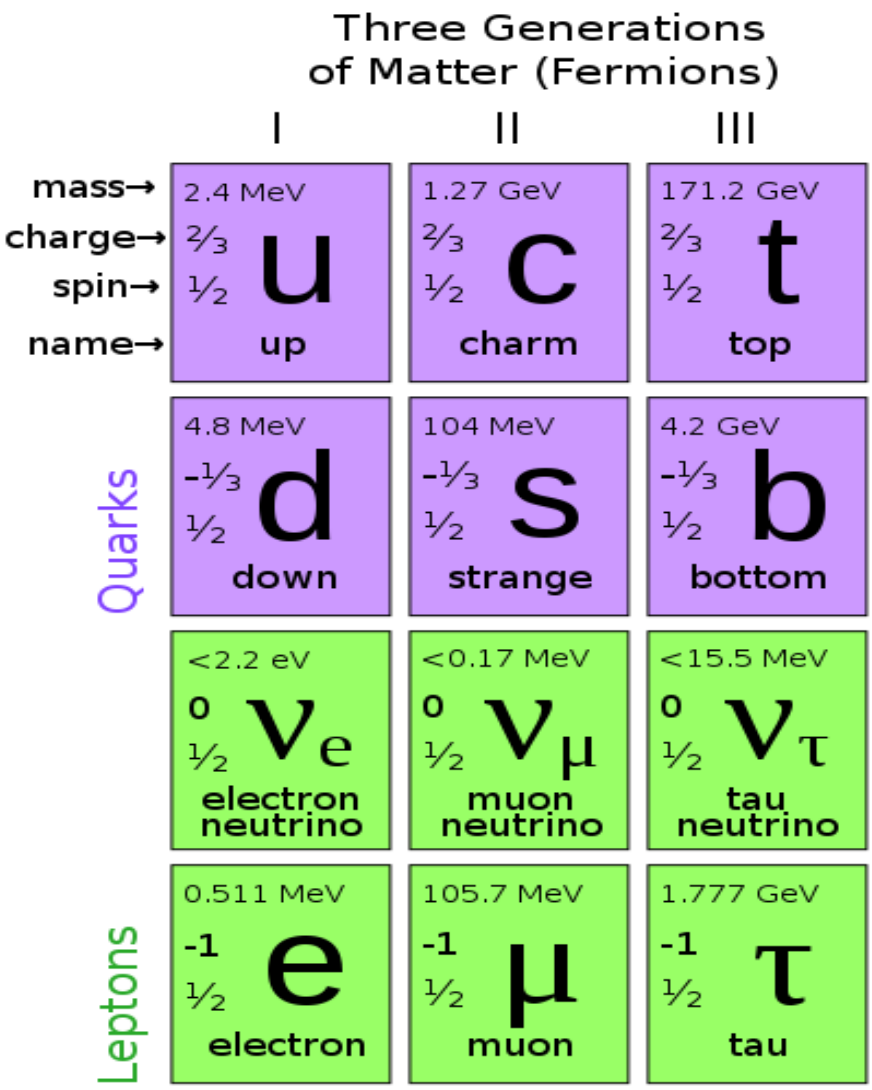



**Figure 7: The elementary particles of the Standard Model**

## Homework 2: The Standard Model of particle physics

- In your own words, describe the Standard Model of particle physics, and explain why it is important to understand how matter is organised. [20 marks]

- Describe the fundamental particles in the Standard Model. Think of:
  - Their charge, and how they are different from proton and neutron charges.
  - Their spin (you might want to do your own research in the Internet to find out what this is).
  - Their mass. [20 marks]

- Protons and neutrons are made up of three first generation quarks. What is the quark composition of a proton? What is the quarks composition of a neutron? (Think of how you can put up three quarks together to have the right electric charge of a proton and of a neutron). [20 marks]

- Draw a diagram describing and explaining how the matter in your body is structured, from the level of body cells, to the level of quarks and leptons. Indicate the different scales involved. [20 marks]

- Go to the CERN website https://home.cern/students-educators and try to find the names and compositions of at least five different particles physicists work with at CERN and that you didn't know about before. [20 marks]

# Tutorial 3 – The fundamental interactions

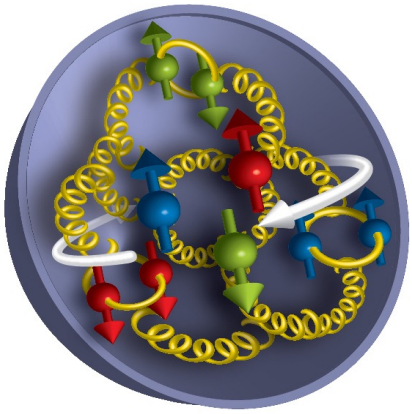


**Figure 8: Quarks and gluons inside a nucleon**

## Today's Key Questions:

- What are the fundamental interactions of Nature?
- How many fundamental interactions are there?
- How do they work?
- What is particle exchange?

## What is the Purpose of Tutorial 3?

- Understand the fundamental interactions.
- Understand which particles interact through which interaction.
- Understand particle exchange.
- Understand over which scales each interaction works.

## Fermions and bosons

The fundamental particles are divided into two big types:

- Fermions: they are quarks or leptons, and we saw them in the previous tutorial. They make up the matter that we see around us.

- Bosons: they are responsible for the interactions that hold matter together, and we will study them in this tutorial.

## Activity 1: Brainstorming – Fundamental Interactions

In groups:

- Discuss which interactions you know about already. You might want to consider the following questions: Which force holds galaxies together? What keeps electrons around atomic nuclei? What holds atomic nuclei together? What causes radioactive decay?

- For the interactions that you thought about, could you tell which one has the longest range? Which one is the strongest overall? What "types" of matter each interaction "cares about"?

## The fundamental interactions

The Standard Model classifies not only fundamental fermions that make up matter (quarks and leptons), but also the fundamental bosons that hold matter together. The complete table is given in Figure 9.

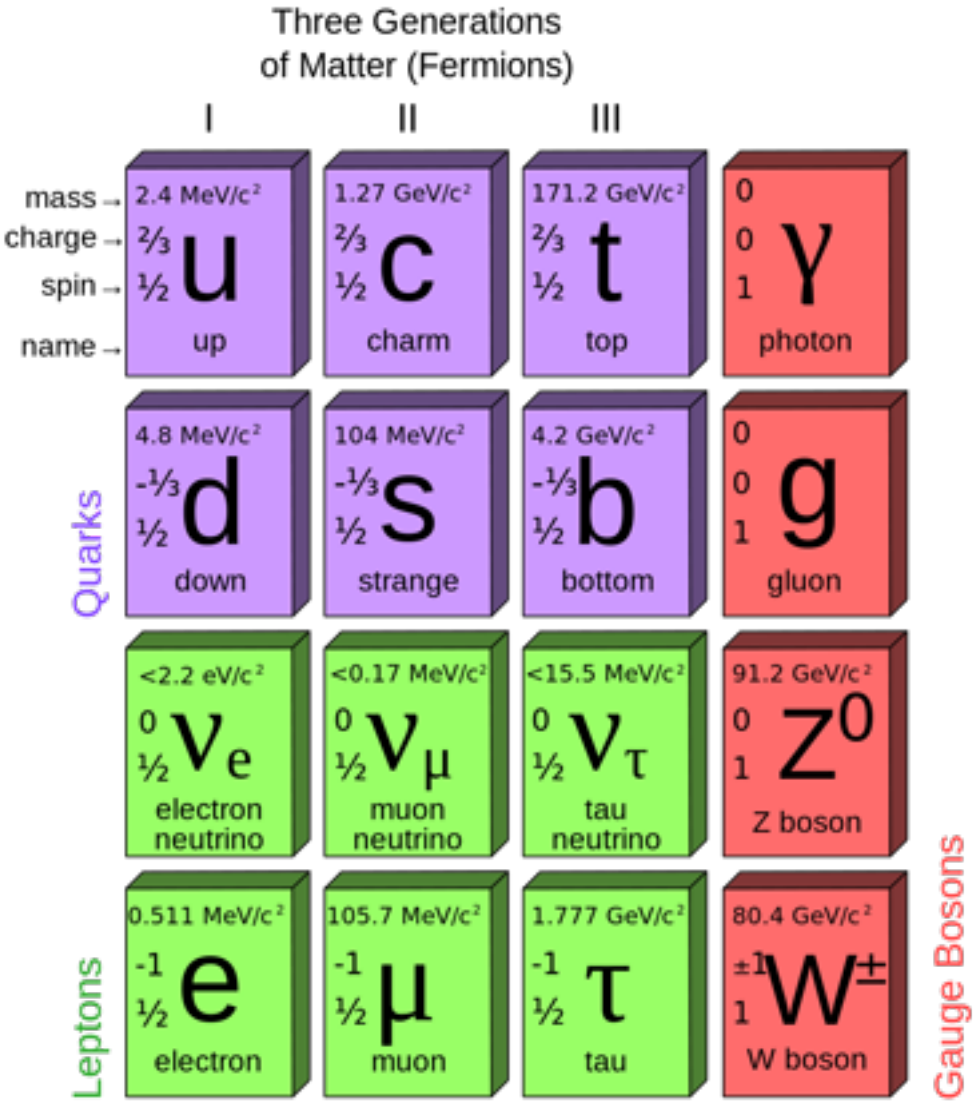



**Figure 9: Matter and interaction particles in the Standard Model**

Fermion particle interactions are said to be mediated by a gauge boson particle. The rules are that the corresponding charge has to be conserved at each point of interaction.

## Activity 2 – Think, pair, share

In pairs, discuss the following questions:

- Which interaction can the photon mediate? What is the condition on the electric charge?
- Which interaction does the gluon mediate? What is the condition on the particles' charge?

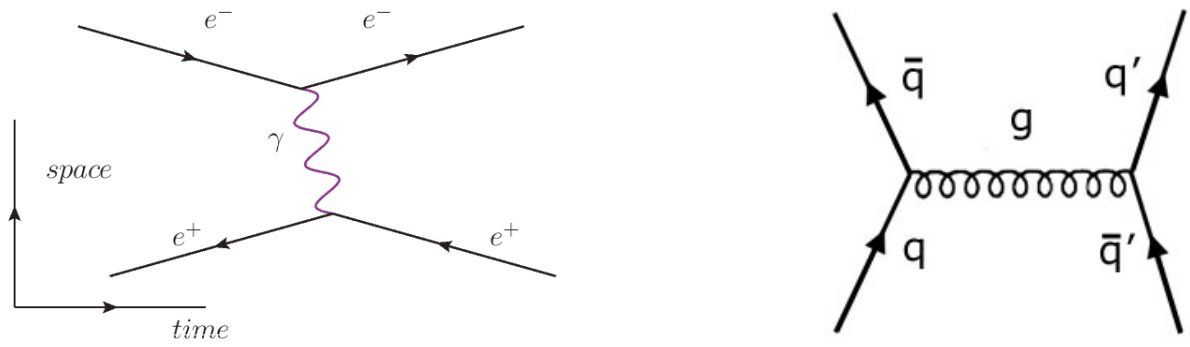



**Figure 10: Diagrams depicting fundamental interactions**

## Particle decay

Fundamental interactions are responsible not only for the forces that hold matter together, but also for particle decay. Many fundamental particles 'decay', going from a heavy particle to a lighter particle. This happens ***VERY*** rapidly, meaning in everyday life we only ever see the lowest mass fundamental particles.

An analogy of 'particle decay' can be made by considering how money can be split into smaller units:

- Start with a £1 coin. This can be split into two 50p coins.
- A 50p coin can be split into two 20p and one 10p.
- The 10p can be split into two 5p.
- The 5p can be split in two 2p and one 1p.
- The 1p coin is the smallest we can go. It cannot split into anything smaller.

When a particle decays it must follow certain rules that determines what it can decay into.

- A particle can decay into 'daughter' particles. The total mass can only decrease; it can never increase: A heavy particle can only decay into lighter particles. Any reduction in mass is converted into energy.
- Electric charge 'conservation' rule: Electric charge is always conserved: A particle can only decay into particles with the same total electric charge.

## Activity 3 – Particle decay

Consider the following particle decays, and answer whether each of the decays is possible. Refer to the Standard Model table to check that the conditions for particle decay are satisfied.

- A bottom quark decaying into a charm quark and a $W^-$ boson.
- A charm quark decaying into a strange quark and a $W^+$ boson.
- A strange quark decaying into an up quark and a $W^-$ boson.

## Homework 3: Fundamental Interactions

- In your own words, describe and explain what is meant by fundamental interactions and particle mediation. [20 marks]

- Draw decay diagrams for the following processes:
  - A bottom quark decaying into a charm quark and a $W^-$ boson.
  - A charm quark decaying into a strange quark and a $W^+$ boson.
  - A strange quark decaying into an up quark and a $W^-$ boson. [30 marks]

- For the decay processes in the previous question, compute the total energy of the decaying particle, and the sum of energies of the decay products. You should use Einstein's equation.

[30 marks]

- What are the similarities you can think of between particle interactions and decay, and balancing chemical equations? What is conserved in each case?

[20 marks]

# Tutorial 4 – Particle Accelerators

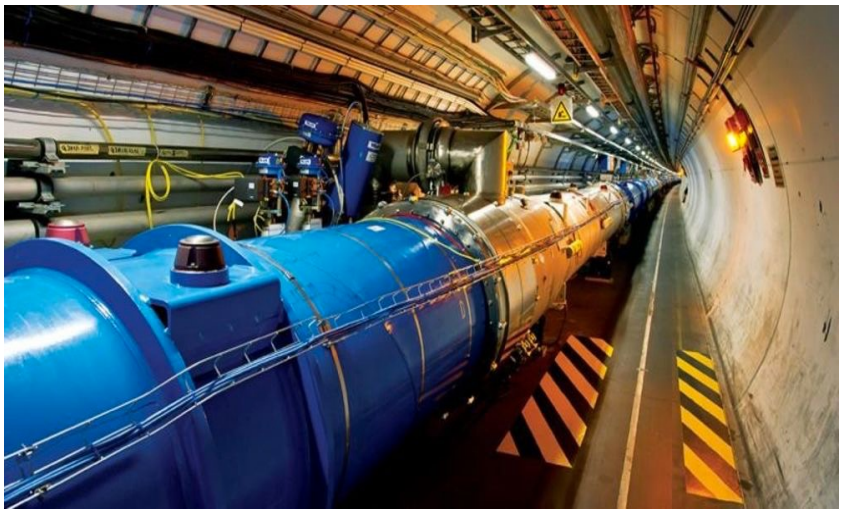


**Figure 11: A section of the LHC in Geneva**

## Today's Key Questions:

- What is a particle accelerator?
- How does it work?
- Where are today's biggest accelerator?
- What does a particle physicist do?

## What is the Purpose of Tutorial 4?

- Understand energy and particle collisions.
- Understand how to search for elementary particles.

## What are particle accelerators, and why do scientists need them?

Scientists want to find out what matter is made of, that is they need to discover the most elementary parts of matter. To do that, they make particles collide with each other and see what new heavy particles are produced in these collisions. To create these new heavy particles, scientists accelerate protons through very strong electric fields.

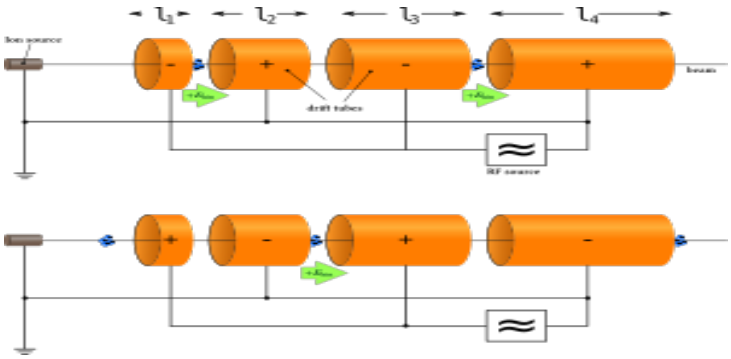


**Figure 12: A series of electric fields to accelerate protons**

## Activity 1 – Accelerating protons through a linear collider

In pairs, discuss and answer the following questions:

- What kind of electric field do you need to accelerate a proton (which is positively charged)?

- The formula for kinetic energy is

$$E = \frac{1}{2}mv^2$$

  What is the kinetic energy of a proton travelling at a speed v = 100 000 000 m x $s^{-1}$? And that of a proton travelling at a speed v = 200 000 000 m x $s^{-1}$? What about v = 290 000 000 m x $s^{-1}$?

- The formula for the energy gained by a proton accelerated through an electric field V is

$$E = qV$$

  where q is the electric charge of the proton. What is the strength of the electric field you need to accelerate a proton to v = 290 000 000 m x $s^{-1}$?

## Improving on a linear collider

One of the problems with a linear collider is that you need extremely long distances to accelerate protons to speeds close to the speed of light in order to get the amount of energy necessary to produce new heavy particles. One solution to the problem is to combine electric fields with magnetic fields into a circular collider.
In a circular collider, protons are accelerated by strong electric fields and kept in a circular orbit by magnetic fields. Protons can then be accelerated to very high speeds by circling many times through the circular collider.

## Activity 2 – Simulating a magnetic field in a circular collider

- Work in a group and stand in a circle. Hold your right hand down by your side. This hand represents a negative (or low) electric charge. Have your left hand in the air. This hand represents a positive (or high) electric charge. If you are holding the proton your down (negative) hand you must pass to your up (positive) hand. A positively charged proton in your high (positive) hand can only be passed to someone else's low (negative) hand. Again, as the 'proton' moves around the circle it gains more and more energy, i.e. its speed increases. You can move the 'proton' around the circle as often as you want, adding more energy with each circuit.

- Next, make the proton follow a curved path with a magnet. Fleming's Left-Hand Rule describes how a *current* in a magnetic *field* creates a force. A proton has a positive charge, and therefore creates a current when the proton is moving. When the proton moves in a direction perpendicular to a magnetic field it is subject to a force that pushes the proton in a direction perpendicular to its direction of travel and the magnetic field.

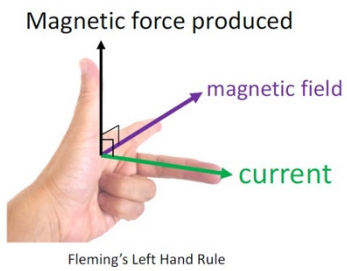



**Figure 13: Fleming's Left Hand Rule**

- Use your left hand and your fingers positioned as shown. (The first and second fingers and thumb are

orthogonal). Point your **F**orefinger ('**F**ield') in front. Point your se**C**ond finger to your right, indicating the direction of the **C**urrent. Your **T**humb is now showing the upward direction of the force that drags the proton to follow a curved path. As the 'particle' continues travelling to the right and away from you it will follow a curved path.

## The Large Hadron Collider (LHC) in Geneva

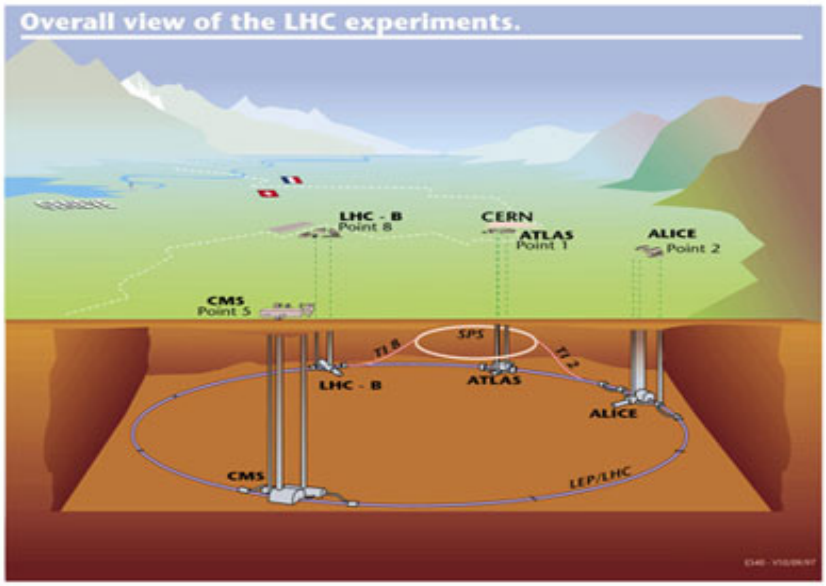



**Figure 14: The LHC experiment in Geneva**

The Large Hadron Collider (LHC) at CERN near Geneva accelerates protons formed by ionising hydrogen atoms to speeds approaching that of light, before colliding the particles together. The temperature of these collisions is thought to be comparable to that a millionth of a second following the Big Bang. Detectors in the LHC measure particles resulting from the collisions. Scientists use this data to develop further explanations of what happened at the moment following the Big Bang, and the state of matter at that time.

The Large Hadron Collider (LHC) is probably the largest and most complex machine ever constructed. Thousands of engineers and scientists from countries from all around the world spent over 25 years on its design and construction. The LHC name is derived from:

- 1) The 27 km circumference underground tunnel in which particles circulate (hence 'Large')
- 2) The particles that are accelerated to high velocity are protons (a proton is a 'Hadron')
- 3) It causes two protons to crash into each other (hence 'Collider')

## Homework 4: Particle Accelerators

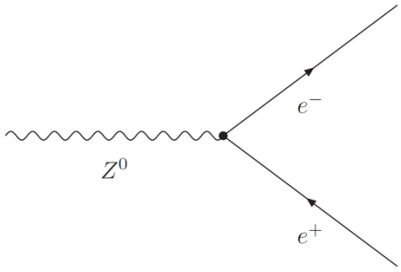
- In your own words, describe how a particle accelerator works. Why do scientists use strong electric fields? Why do they need magnetics fields? Why do they collide high energy protons and not low energy protons? [20 marks]

- In the LHC, protons are accelerated to approximately 290 000 000 m x $s^{-1}$.
    - How long does it take for a proton to go once around the ring?
    - How many times per second does a proton circle the LHC ring? [20 marks]

- When particles collide in a particle accelerator, the new heavy particles produced often decay very fast to some other lighter particles, following a decay chain. However, the mass of the original heavy particles can be reconstructed from the masses of the decay products using the formula

$$M = \sqrt{2Energy_1 \times Energy_2(1 - \cos\theta)}$$

where M is the mass of the original heavy particle, $Energy_{1,2}$ are the energies (in MeV) of the decay products, and θ is the angle between the decay products. Using this formula, reconstruct the mass of the $Z^0$ boson from the decay in the following diagram (for $\theta = 90^0$).




[30 marks]

- In a particle accelerator like the LHC, the chance of single particles colliding is very, very small. The diameter of a protons is approximately $10^{-15}$ m (i.e. 1/1,000,000,000,000,000 m), so there isn't much chance of two protons hitting each other. If the chance of two protons hitting each other is $10^{-11}$ , which strategy could you follow to get at least one proton-proton collision per round? Justify and articulate your answer. [30 marks]

# Tutorial 5 – From the Big Bang to today

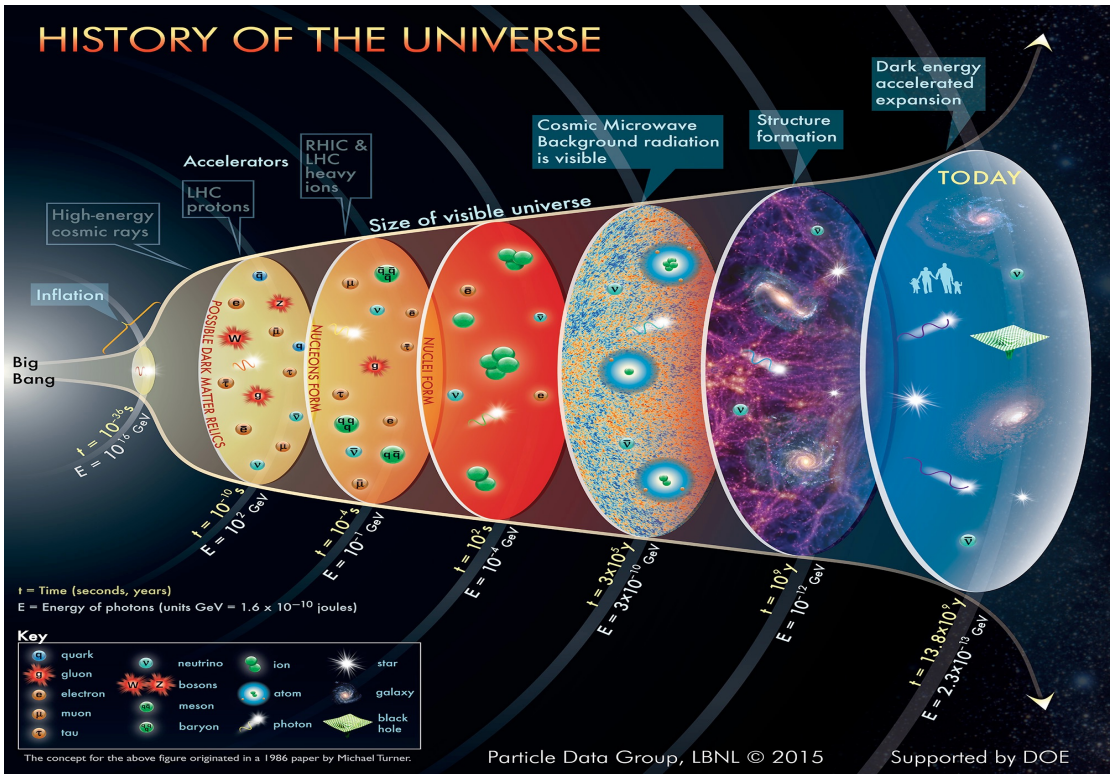



**Figure 15: A brief history of the Universe after the Big Bang**

## Today's Key Questions:

- What is the Big Bang?
- What did the Universe evolve?
- How was today's matter formed?

## What is the Purpose of Tutorial 5?

- Understand the density and temperature conditions at the Big Bang
- Understand the expansion of the Universe
- Understand the history of the Universe and how matter was formed

## What is the Big Bang?

The Big Bang Theory is the commonly accepted scientific model for the creation and evolution of the Universe. The Big Bang Theory says that the Universe started in an extremely dense and hot state in which all the matter and gas that we see in the Universe now was concentrated in a single point in space, known as the Singularity. At the time of the Singularity, matter as we know it was not yet formed, and all the elementary particles were not bound together but set loose in a state similar to that of a gas.

## Activity 1 – The density and temperature at the time of the Big Bang

- At the time of the Big Bang, everything (i.e. all the matter that now fills our Universe) was in a state of gas at an incredibly high matter density D = 8 x $10^{19}$ Kg / $m^3$. The temperature of a gas of this density is found by the Stefan-Bolzmann formula (you can ask as to how this formula is derived)

$$\rho = \frac{4\sigma}{c} T^4$$

where $\rho = D \times c^2$ (remember Einstein's equation, again!) and $\sigma = 5.67 \times 10^{-8}$ W / m$^2$ / K$^4$. Calculate the temperature of the gas at the time of the Big Bang. (If you want to make a comparison, the temperature of the Sun is around 5800 K).

## The expansion of the Universe

Because of the incredibly high densities and temperatures at the time of the Big Bang, the Universe started expanding. Because the volume of the Universe increased with this expansion, the density and the temperature decreased during the expansion. As a result, the elementary particles in the initial state of gas started forming protons, neutrons and electrons though the fundamental interactions (electromagnetic, strong and weak interactions). This phase is known as baryogenesis.

Cosmic microwave background radiation provides further evidence for the Big Bang theory. As the Universe expanded it cooled down and atoms started to form. The Universe became less dense, and light was able to travel through — the Universe became transparent rather than opaque. The most distant light we can see, emitted from the Universe as it became transparent, is CMBR. We can measure the temperature of CMBR and map the cooling of the Universe, showing CMBR to be radiation 'left over' from the Big Bang.

From the Big Bang explanation we can predict that the first elements to be formed would have been the lightest ones (hydrogen, helium) and calculate the amount of hydrogen and helium that should be found in the Universe (75% and 25% respectively). We are able today to measure the amounts of these elements in the Universe, which match the prediction, thus providing further evidence for the Big Bang.

## Activity 2 – Modeling the expansion of the Universe

- Six students stand in a line each representing galaxies. The students are each linked by holding a light rope or string between them (i.e. n students need n-1 strings). Each student then moves to twice the previous distance (use knot in middle of a longer string). Students at both ends notice that the more distant student has moved further in the same time, i.e. they are moving faster. Additionally, an extra student measures how far from one end each student has moved in this single step (time). The doubling of distances between galaxies represents expansion of space.

- We will model expansion of the Universe using balloons. A partially inflated balloon with a grid or dots drawn on it is fully inflated — the further away the dots are from a given reference dot, the greater the expansion in a given 'inflation spurt'.

## Measuring the expansion of the Universe

The Hubble telescope Deep Field image provides insight into the behaviour of distant galaxies when combined with our knowledge of atomic structure, the electromagnetic spectrum, and line spectra. Red-shift provides the first piece of evidence for the 'stretching' of space — the Universe is expanding.

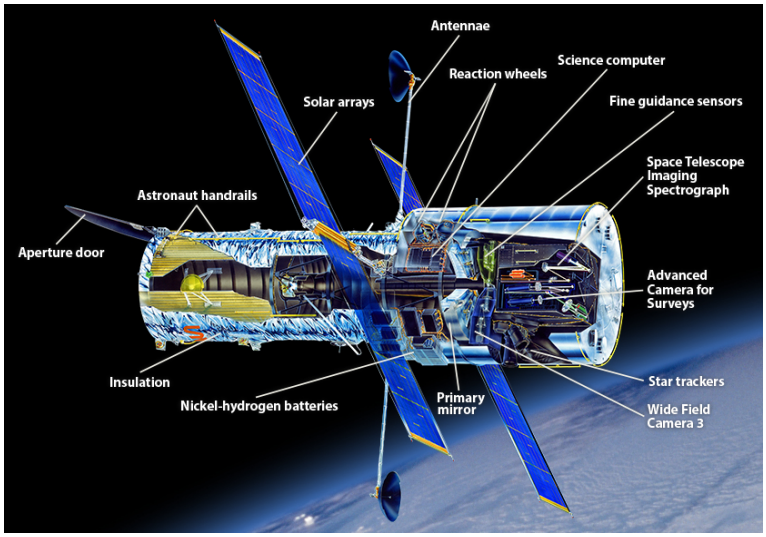



**Figure 16: The Hubble space telescope**

## Activity 3 – Red-shift and Doppler effect

Working in pairs, discuss the following:

- When an ambulance drives towards you, you may have noticed that the pitch of the siren is higher than when the ambulance is moving away from you. What kind of waves is the siren producing? What does this have to do with the red shift that is observed between galaxies moving away from each other in the Universe?

## Further evidence for the expansion of the Universe

Type 1A supernovae are the 'standard candles' that enable us to measure distance to galaxies. Using supernovae measurements we can see that the further we look out into space the faster galaxies appear to be moving away. The method of using a 'standard candle' to measure distance depends on the fact that the brightness of the 'candle' depends on its distance away from the observer. A supernova is the explosion of a massive star at the end of the fusion processes. Because scientists know the brightness of a supernova when it occurs, this enables us to deduce the distance away. The red-shift of neighbouring stars in the galaxy enables us to work out the speed. Red-shift and Type 1A supernovae suggest that space may have had a beginning, with all matter in the Universe together about 13.7 billion years ago —evidence for the Big Bang.

## Activity 4 – Standard Candles

We will use torches to model 'standard candles'. We set up identical torches at various positions across the classroom and then ask a fellow student to lie down on the floor and say which torches are closest and so on. Alternatively we use a light meter for quantitative data.

## Homework 5: Final assignment

- In this final assignment, in groups of two, you will work together and gather in a coherent structure what you learned in the five tutorials.

- You need to put up a professional poster, summarizing the elementary particles and interactions that you have learned about in the course of the previous tutorials, and how matter was formed in the course of the evolution of the Universe.

- You should include two to three sections explaining the physical theory and concepts that you have learned about, including diagrams and explanations of these diagrams.

- You should also include an experimental section explaining how scientists have validated the key scientific concepts that you explained in your theoretical sections.

- Your poster should be professional looking, with clear diagrams and explanations, and if possible typeset in a professional word processing program.

- Then, you should prepare a 20 minute presentation containing clear explanations and deliver it to your fellow students.

## The Deadline is:

# Tutorial 6 – Feedback

## What is the Purpose of Tutorial 6?

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

## What are the key questions?

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

## Activity 1 – Marking your own

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

**What went well?**

1.

2.

3.

**What could be improved?**

1.

2.

3.

## Activity 2 – Responding to feedback

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

## Activity 3 – Looking Forwards: Think, Pair Share

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

# Appendix 1 – Referencing correctly

When you get to university, you will need to include references in the assignments that you write, so we would like you to start getting into the habit of referencing in your Brilliant Club assignment. This is really important, because it will help you to avoid plagiarism. Plagiarism is when you take someone else's work or ideas and pass them off as your own. Whether plagiarism is deliberate or accidental, the consequences can be severe. In order to avoid losing marks in your final assignment, or even failing, you must be careful to reference your sources correctly.

## What is a reference?

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

## Why should I reference?

Referencing is important in your work for the following reasons:

- It gives credit to the authors of any sources you have referred to or been influenced by.
- It supports the arguments you make in your assignments.
- It demonstrates the variety of sources you have used.
- It helps to prevent you losing marks, or failing, due to plagiarism.

## When should I use a reference?

You should use a reference when you:

- Quote directly from another source.
- Summarise or rephrase another piece of work.
- Include a specific statistic or fact from a source.

## How do I reference?

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

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

**Bibliography**: This is just a list of the references you have used in your assignment. In the bibliography, you list your references by the numbers you have used, and include as much information as you have about the reference. The list below gives what should be included for different sources.

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

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

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

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

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

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

# Appendix 2 – University Applications Guidance

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

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