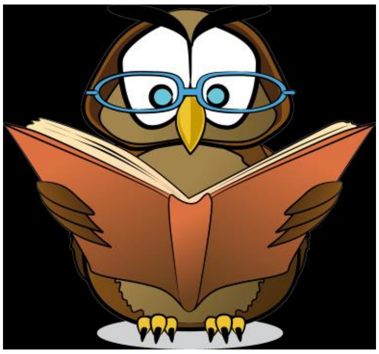


KNOWLEDGE

ST MARY’S SCIENCE DEPARTMENT: PHYSICS

A LEVEL PHYSICS

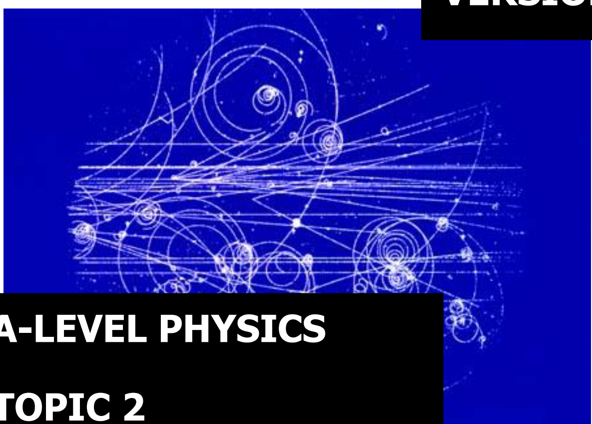
BRIDGING COURSE

PARTICLES AND RADIATION

WEEK 1

NAME	
PHYSICS CLASS	

VERSION 1.2



A-LEVEL PHYSICS

TOPIC 2

BRIDGING WORK

THIS MUST BE BROUGHT TO PHYSICS LESSONS AT THE START OF YEAR 12.

WEEK 1
Contents

Overview

This bridging course will provide you with a mixture of information about A-level Physics, and what to expect from the course, as well as key work to complete. Students who are expecting to study Physics at A-level, and are likely to meet the entry requirements, must complete the bridging course fully and thoroughly, to the best of their ability.
You should complete all work on paper and keep it in a file, in an ordered way. You will submit it to your teacher in September.

All of the work will be reviewed, and selected work will be assessed, and you will be given feedback on it. This work will be signalled to you. If you do not have access to the internet, please contact the school and appropriate resources will be sent to you.

If you are thinking about studying Physics at A-level, you should attempt this work to see whether or not you think studying a subject like this is right for you. If you later decide to study Physics, you must ensure you complete this work in full.

This work should be completed after you have read and completed the Study Skills work that all of Year 12 should complete.

Course Overview

To successfully achieve a qualification in A-Level Physics students must carry out two years of studies (Year 12 and Year 13) and carry out 3 assessments at the end of the course based on the specification below.

In addition, students must carry out a list of 12 required practical activities that they must carry out. Exam questions will be based on these practicals. 6 practicals will be carried out in Year 12 and 6 practicals will be carried out in Year 13.

If successful, students will receive a practical endorsement along with their A-Level Physics qualification.

First year of A-level

1. Measurements and their errors, including use of SI units and their prefixes, limitations of physical measurement, estimation of physical quantities

2. Particles and radiation, including constituents of the atom, particle interactions, collisions of electrons with atoms.

3. Waves, including progressive waves, interference, diffraction.

4. Mechanics and energy, including projectile motion, Newton's laws of motion.

5. Electricity, including current/ voltage characteristics, circuits, electromotive force and internal resistance.

Second year of A-level

6. Further mechanics and thermal physics, including periodic motion, thermal energy transfer, and molecular kinetic theory model.

7. Fields, including Newton's law of gravitation, orbits of planets and satellites, magnetic flux density.

8. Nuclear physics, including evidence for the nucleus, radioactive decay, nuclear instability.

Plus one option from:

• Astrophysics, including classification of stars by luminosity, Doppler Effect, detection of exoplanets.

• Medical physics, including physics of vision, ECG machines, x-ray imaging.

• Engineering physics, including rotational dynamics, thermodynamics and engines.

• Turning points in physics, including discovery of the electron, Einstein's theory of special relativity.

• Electronics, including discrete semiconductor devices, data communication systems.

Assessment Schedule

To gain a qualification in A Level Physics – you must sit **three** examinations.

Paper 1	+	Paper 2	+	Paper 3
Content • Topics 1 – 5 • and periodic motion		**Content** • Topics 6 – 8		**Content** • Practical skills • Data analysis • Optional topic
Assessment • Written exam: 2 hours • 85 marks • 34% of A-level		**Assessment** • Written exam: 2 hours • 85 marks • 34% of A-level		**Assessment** • Written exam: 2 hours • 80 marks • 32% of A-level
Questions • 60 marks: a mixture of short and long answer questions • 25 marks: multiple choice questions		**Questions** • 60 marks: a mixture of short and long answer questions • 25 marks: multiple choice questions		**Questions** • 45 marks: questions on practical experiments and data analysis • 35 marks: questions on optional topic

The marks awarded on the papers will be scaled to meet the weighting of the components.

Students' final marks will be calculated by adding together the scaled marks for each component. Grade boundaries will be set using this total scaled mark. The scaling and total scaled marks are shown in the table below.

Component	Maximum raw mark	Scaling factor	Maximum scaled mark
Paper 1	85	x1	85
Paper 2	85	x1	85
Paper 3: Section A	45	x1	45
Paper 3: Section B (Astrophysics – option)	35	x1	35
Paper 3: Section B (Medical physics – option)	35	x1	35
Paper 3: Section B (Engineering physics – option)	35	x1	35
Paper 3: Section B (Turning points in physics – option)	35	x1	35
Paper 3: Section B (Electronics – option)	35	x1	35
		Total scaled mark:	250

Aim

In this bridging course, we will outline the basic principles of the four key topics covered in Year 12 Physics.

In each topic, we will start by reviewing the understanding which you gained in GCSE Physics and apply it to more advanced applications found in A-Level Physics.

This is not a comprehensive overview of the A-Level Physics specification, rather a taster on what is covered throughout the course.

This bridging course should give you an experience of the level you will be expected to study at, at the start of Year 12

Important

Please remember to look after your own wellbeing as you work through this bridging course.

Please take regular breaks as you go through this work.

This work should take approximately 5 hours, so should not be completed in one sitting.

Do not worry or panic if there is something challenging or which you do not understand at first. This is completely normal.

If you do not understand a concept after reviewing this work, please contact Mr. Turnbull on his school e-mail address.

WEEK 1: PARTICLES

Definition List

Definitions you must learn:

Key Word	Definition
Isotopes	Nuclides with the same number of protons but different number of neutrons.
Specific Charge	The (overall) charge to mass ratio of a particle. $= \frac{\text{Overall Charge}}{\text{Rest Mass}}$
Exchange Particle	A particle which transmits a fundamental force in the Universe. Also known as a virtual boson.
Feynman Diagram	A diagram which shows a particle interaction over time.
Fundamental force	A force which persists throughout the Universe due to the movement of exchange particles between other particles.

IMPORTANT

A video of Mr. Turnbull going through this book can be found here.

SCAN ME

TOPIC: 3.2.1.1 Constituents of the Atom

SPEC CHECK

Specification	Completed?
Simple model of the atom, including the proton, neutron and electron. Charge and mass of the proton, neutron and electron in SI units and relative units.	
Specific charge of the proton and the electron, and of nuclei and ions.	
Proton number Z, nucleon number A, nuclide notation.	
Meaning of isotopes and the use of isotopic data.	

Student Checklist

Complete the following before attempting any work on this section.

Have I…….	Yes or No?
Read through the notes of this section?	
Highlighted/underlined the key concepts of this section?	
Made my own notes based on the notes of this section?	

Complete the above checklist with the notes of each section before you attempt to answer any questions on this section of work.

The Nuclear Model

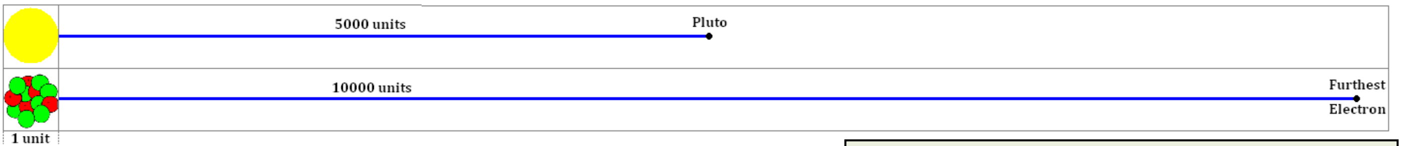
Prior Knowledge Link
This is a topic found in a previous GCSE module **- Radioactivity**

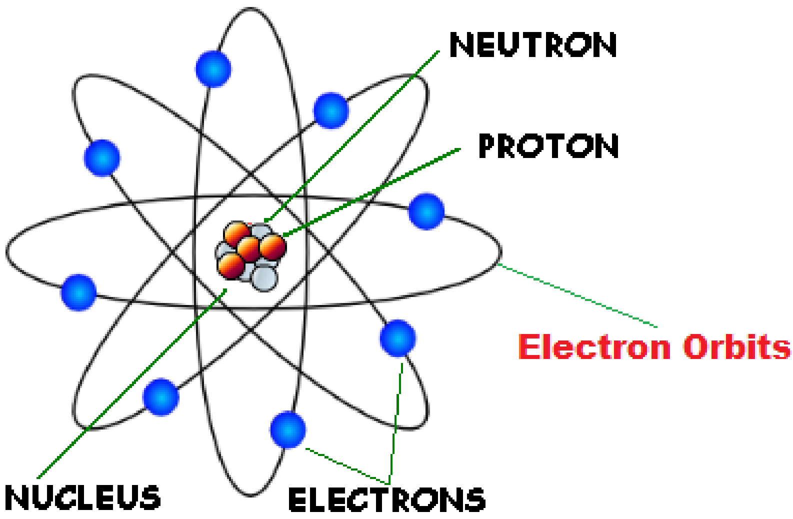
We know from Rutherford's experiment that the structure of an atom consists of positively charged protons and neutral neutrons in one place called the nucleus. The nucleus sits in the middle of the atom and has negatively charged electrons orbiting it.

At GCSE, we used charges and masses for the constituents relative to each other, the table above shows the actual charges and masses.

Almost all the mass of the atom is in the tiny nucleus which takes up practically no space when compared to the size of the atom. If we shrunk the Solar System so that the Sun was the size of a gold nucleus the furthest electron would be twice the distance to Pluto.

If the nucleus was a full stop it would be 25 m to the first electron shell, 100 to the second and 225 to the third.





The electrons exist in energy levels (or orbitals) around the nucleus.

They do not orbit as shown in this picture.

In an orbital, an electron exists with a particular energy; it does not lose or gain energy when in the level.

The further away from the nucleus, the greater the energy the electron has.

Electrons can move between energy levels by either gaining (excitation) or losing energy (de-excitation).

Physics Tip

Electrons are considered fundamental.

This is a particle which cannot be split up into anything smaller.

Physics Tip

When calculating the mass of an atom or an ion, the mass of the electrons is very small compared to the mass of the nucleus.

So, you only need to use the mass of the nucleus when calculating the specific charge.

Prior Knowledge Link
This is a topic found in a previous GCSE module **- Radioactivity**

Notation

We can represent an atom of element X in the following way:

$$^{A}_{Z}X$$

Z is the proton number. This is the number of protons in the nucleus.
In an uncharged atom, the number of electrons orbiting the nucleus is equal to the number of protons.
In Chemistry, it is called the atomic number

A is the nucleon number. This is the total number of nucleons in the nucleus (protons + neutrons) which can be written as A = Z + N.
In Chemistry, it is called the atomic mass number

N is the neutron number. This is the number of neutrons in the nucleus.

Isotopes

Prior Knowledge Link
This is a topic found in a previous GCSE module **- Radioactivity**

Isotopes are different forms of an element.
They always have the same number of protons but have a different number of neutrons.

Since they have the same number of protons (and electrons) they behave in the same way chemically.

Isotopes have different behaviour during nuclear decay however.

Chlorine

If we look at Chlorine in the periodic table, we see that it is represented by $^{35.5}_{17}Cl$.
How can it have 18.5 neutrons? It can't!
There are two stable isotopes of Chlorine, $^{35}_{17}Cl$ which accounts for ~75% and $^{37}_{17}Cl$ which accounts for ~25%.
So, the average of a large amount of Chlorine atoms is $^{35.5}_{17}Cl$.
The nucleon number shown on the Periodic Table is an average value based on the different types of isotopes and their relative abundance on Earth.

Examination Hint

It is a common examination question to define an isotope.

An isotope has the same number of protons (1 mark) but a different number of neutrons (1 mark).

Isotopes exhibit similar chemical properties but different radioactive properties.

Specific Charge

Specific charge is another name for the charge-mass ratio.

Physics Tip

In physics, 'specific' mostly means 'per unit mass'.

Study Tip

You will be given the mases (in kg) of all particles and the charge (in C) in the data and formulae booklet.

This is a measure of the charge per unit mass and is simply worked out by worked out by dividing the charge of a particle by its mass.

Specific Charge = Overall Charge (In C) / Mass (In kg)

Study Tip

You are **not** given this equation in the equation book.

You can think of it as a how much charge (in Coulombs) you get per kilogram of the 'stuff'.

Constituent	Charge (C)	Mass (kg)	Charge-Mass Ratio ($C\ kg^{-1}$) or (C/kg)	
Proton	1.6×10^{-19}	1.673×10^{-27}	$1.6 \times 10^{-19} \div 1.673 \times 10^{-27}$	9.58×10^{7}
Neutron	0	1.675×10^{-27}	$0 \div 1.675 \times 10^{-27}$	0
Electron	(-) 1.6×10^{-19}	9.1×10^{-31}	$1.6 \times 10^{-19} \div 9.11 \times 10^{-31}$	(-) 1.76×10^{11}

We can see that the electron has the highest specific charge and the neutron has the lowest.

The larger the specific charge, the more particle is affected by the electric/magnetic field.

Examination Tip

When answering an examination question read whether the specific charge is concerning the atom, the ion or the nucleus.

An atom has no specific charge as it has no overall charge.

For a nucleus, you must use the number of protons as the basis for working out the overall charge.

For an ion, you must use the number of electrons gained or lost as the basis for working out the overall charge.

Examination Tip

In an examination, you will be given the masses of all three particles in kilograms and the charge of an electron in coulombs in the data and formulae booklet in the exam.

You will be given their relative masses or charges though – so learn the numbers.

Examination Tip

When calculating specific charge, make sure the charge and the mass are in the right units.

Ions

Prior Knowledge Link
This is a topic found in a previous GCSE module **- Radioactivity**

An atom may gain or lose electrons. When this happens, the atoms become electrically charged (positively or negatively). We call this an ion.

Physics Tip

The charge should be always been given in Coulombs. Remember 1 charge unit at GCSE = 1.6×10^{-19}C

If the atom gains an electron there are more negative charges than positive, so the atom is a negative ion.

Gaining one electron would mean it has an overall charge of **-1**, which means **-1.6×10^{-19}C**.
Gaining two electrons would mean it has an overall charge of **-2**, which means **-3.2×10^{-19}C**.

If the atom loses an electron there are more positive charges than negative, so the atom is a positive ion. This happens when electrons are given enough energy to escape the positive attraction of the nucleus – the closer to the nucleus, the more energy is needed to be given.

Losing one electron would mean it has an overall charge of **+1,** which means **$+1.6 \times 10^{-19}$C**.
Losing two electrons would mean it has an overall charge of **+2**, which means **$+3.2 \times 10^{-19}$C**.

Physics Tip

Ionisation is normally caused by the atom colliding with a free-moving electron and giving the atom its energy.

VIDEO

To watch a video looking at this concept, please scan one of the following codes with your smartphone.

Note

All rights to this video belong to the creator of the video.

This external third-party content – please check the contents are appropriate.

REVISION SHEET

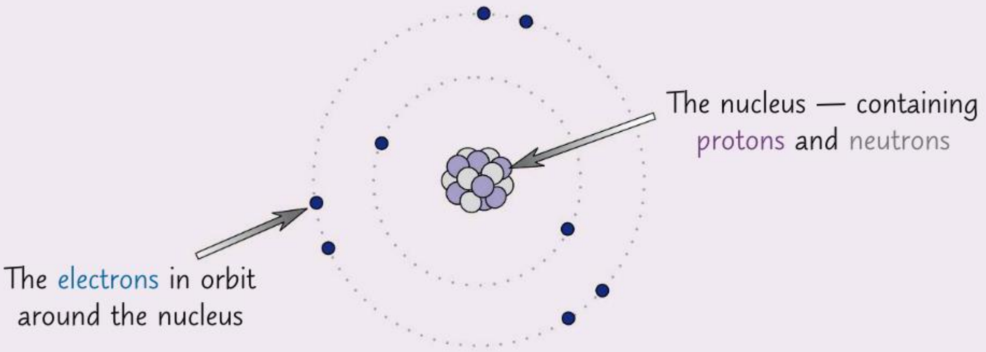
Highlight or underline the key information on the revision sheet to consolidate your understanding.

Atoms are made up of *Protons*, *Neutrons* and *Electrons*

Inside **every atom**, there's a **nucleus** containing **protons** and **neutrons**.
Protons and **neutrons** are both known as **nucleons**. **Orbiting** this core are the **electrons**.

This is the **nuclear model** of the atom.

The diagram shows **neutral oxygen**, with **eight protons** and **eight electrons**.



The particles in an atom have different **properties**. Their charges and masses are so **tiny** that it's often easier to talk about their **relative charge** and **relative mass**.

Particle	Charge (coulombs, C)	Mass (kg)	Relative Charge	Relative Mass
Proton	$+1.60 \times 10^{-19}$	1.67×10^{-27}	+1	1
Neutron	0	1.67×10^{-27}	0	1
Electron	-1.60×10^{-19}	9.11×10^{-31}	–1	0.0005

The Proton Number is the Number of Protons in the Nucleus

No... really.

The **proton number** is sometimes called the **atomic number**, and has the **symbol Z** (I'm sure it makes sense to someone). **Z** is just the **number of protons** in the nucleus.

It's the **proton number** that **defines** the **element** — **no two elements** will have the **same** number of protons.

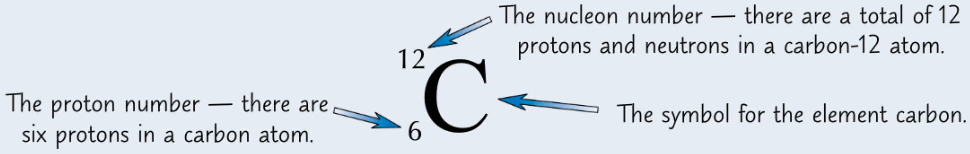
In a **neutral atom**, the number of **electrons equals** the number of **protons**.
The element's **reactions** and **chemical behaviour** depend on the number of **electrons**.
So the **proton number** tells you a lot about its **chemical properties**.

A particle with a different number of electrons to protons is called an ion.

*The **Nucleon Number** is the **Total Number** of **Protons** and **Neutrons***

The **nucleon number** is also called the **mass number**, and has the **symbol A** (*shrug*). It tells you how many **protons** and **neutrons** are in the nucleus. Since each **proton or neutron** has a relative **mass** of (approximately) **1** and the electrons weigh virtually nothing, the **number** of **nucleons** is the same as the **atom's relative mass**.

The nuclide notation of an element summarises information about its atomic structure:



Isotopes have the Same Proton Number, but Different Nucleon Numbers

Atoms with the **same number of protons** but **different numbers of neutrons** are called **isotopes**.

Example: Hydrogen has three natural isotopes — hydrogen, deuterium and tritium.
Hydrogen has 1 proton and 0 neutrons.
Deuterium has 1 proton and 1 neutron.
Tritium has 1 proton and 2 neutrons.

Changing the number of **neutrons doesn't affect** the atom's **chemical** properties.

The **number of neutrons** affects the **stability** of the nucleus though.

Unstable nuclei may be **radioactive** and **decay** over time into different nuclei that are more stable (see p.5).

Radioactive Isotopes Can be Used to Find Out How Old Stuff Is

1) All living things contain the same percentage of radioactive **carbon-14** taken in from the atmosphere.
2) After they die, the amount of carbon-14 inside them **decreases** over time as it **decays** to stable elements.
3) Scientists can calculate the **approximate age** of archaeological finds made from dead **organic matter** (e.g. wood, bone) by using the **isotopic data** (amount of each isotope present) to find the percentage of **radioactive carbon-14** that's **left in** the object.

The Specific Charge of a Particle is Equal to its Charge Over its Mass

The **specific charge** of a particle is the ratio of its charge to its mass, given in coulombs per kilogram ($C\ kg^{-1}$). To calculate specific charge, you just divide the charge in C by the mass in kg.

$$\text{Specific charge} = \frac{\text{charge}}{\text{mass}}$$

You could be asked to find the specific charge of any particle, from a **fundamental particle** like an electron, to the nucleus of an atom or an ion.

A fundamental particle is one that you can't break up into anything smaller.

Example: Calculate the specific charge of a proton.

A proton has a **charge** of $+1.60 \times 10^{-19}$ C and a **mass** of 1.67×10^{-27} kg (see p.2).

So specific charge = $(+1.60 \times 10^{-19}) \div (1.67 \times 10^{-27}) = 9.580... \times 10^{7} = \mathbf{9.58 \times 10^{7}\ C\ kg^{-1}}$ **(to 3 s.f.)**

In calculations, always give your answer to the smallest number of significant

Practice Questions

Credit: CGP Revision Guide Editions

REVIEW QUESTIONS

To assess your understanding, answer the following questions on this topic.

A1. Describe the nuclear model of the atom.

[1 Mark]

....

....

....

A2. State the similarities and differences between the properties of two isotopes of the same element.

[1 Mark]

....

....

....

A3. How do you calculate the specific charge of a particle?

[1 Mark]

....

....

The answers to the review questions are found on the next page.

REVIEW QUESTIONS

A1. Describe the nuclear model of the atom.

[1 Mark]

Inside every atom there is a nucleus which contains protons and neutrons. Orbiting this core are electrons.

A2. State the similarities and differences between the properties of two isotopes of the same element.

[1 Mark]

Same chemical properties.
Different stabilities and physical properties.

A3. How do you calculate the specific charge of a particle?

[1 Mark]

Specific Charge = Overall Charge / Mass

SELF ASSESSMENT

To practice your understanding, answer the following questions.

DO NOT WORRY IF YOU STRUGGLE AT FIRST.

The answers are found after the questions.

A1.1 ion of plutonium $^{239}_{94}Pu$ has an overall charge of $+1.6 \times 10^{-19}$C.

For this ion state the number of

[3 Marks]

(i) protons ....

(ii) neutrons ....

(iii) electrons ....

A1.2 Plutonium has several *isotopes*.

Explain the meaning of the word isotopes.

[2 Marks]

....

....

....

....

Reference: AQA A Level Physics Legacy Papers A

A2.1 A stable atom contains 28 nucleons.

Write down a possible number of protons, neutrons and electrons contained in the atom.

[2 Marks]

.... protons

.... neutrons

.... electrons

An unstable *isotope* of uranium may split into a caesium nucleus, a rubidium nucleus and four neutrons in the following process.

$$^{236}_{92}U \Rightarrow ^{137}_{55}Cs + ^{X}_{37}Rb + 4\,^{1}_{0}n$$

A2.2 Explain what is meant by isotopes.

[2 Marks]

....

....

A2.3 How many neutrons are there in the $^{137}_{55}Cs$ nucleus?

[1 Mark]

....

A2.4 Calculate the ratio $\frac{\text{charge}}{\text{mass}}$, in C kg^{-1}, for the $^{236}_{92}U$ nucleus.

[3 Marks]

....

....

....

A2.5 Determine the value of **X** for the rubidium nucleus.

[2 Marks]

....

X = ...

ANSWERS

A1.1 (i) 94 (protons) **(1)**

(ii) 145 (neutrons) **(1)**

(iii) 93 (electrons) **(1)**

3

A1.2 same number of protons
[or same atomic number] **(1)**

different number of neutrons/nucleons
[or different mass number] **(1)**

2
[5]

A2.1 number of protons = number of electrons (e.g.14) **(1)**

number of protons + number of neutrons = 28 **(1)**

2

A2.2 nuclei with the same number of protons **(1)**
but different number of neutrons/nucleons **(1)**

A2.3 (137 – 55) = 82 **(1)**

A2.4 $\frac{Q}{m} = \frac{92 \times 1.60 \times 10^{-19}}{236 \times 1.67 \times 10^{-27}}$ **(1)**

= 3.73×10^{7} (C kg^{-1}) **(1)**

A2.5 X (= 236 – 137 – 4) = 95 **(1)**

6
[8]

ASSESSMENT QUESTION

Please answer this assessment question on this topic in Physics.

This work will be formally assessed with feedback given.

This work will be submitted at the start of the A-Level course in Year 12.

If we require any help or you wish to receive immediate feedback, please e-mail Mr. Turnbull.

A3.1 The most abundant isotope of cobalt is represented by $^{59}_{27}Co$.

How many protons, neutrons and orbital electrons are there in a neutral atom of this element?

[2 Marks]

.... protons

.... neutrons

.... electrons

A3.2 How is the nuclide that has one less proton than the nickel nuclide, $^{61}_{28}Ni$, represented?

[2 Marks]

....

A3.3 The heaviest isotope of hydrogen, whose nucleon number is 3, is called tritium.
How is tritium represented?

[1 Mark]

....

A3.4 Calculate the charge per unit mass, in C kg $^{-1}$, for a tritium nucleus.

[2 Marks]

....

....

....

....

Reference: AQA A Level Physics Legacy Papers A

TOPIC: 3.2.1.2 Stable and Unstable Nuclei

SPEC CHECK

Specification	Completed?
The strong nuclear force; its role in keeping the nucleus stable; short-range attraction up to approximately 3 fm, very-short range repulsion closer than approximately 0.5 fm.	
Unstable nuclei; alpha and beta decay.	
Equations for alpha decay, $\beta-$ decay including the need for the neutrino.	
The existence of the neutrino was hypothesised to account for conservation of energy in beta decay.	
Demonstration of the range of alpha particles using a cloud chamber, spark counter or Geiger counter.	
Use of prefixes for small and large distance measurements.	

Student Checklist

Complete the following before attempting any work on this section.

Have I…….	**Yes or No?**
Read through the notes of this section?	
Highlighted/underlined the key concepts of this section?	
Made my own notes based on the notes of this section?	
Brought the notes to be used in lesson?	

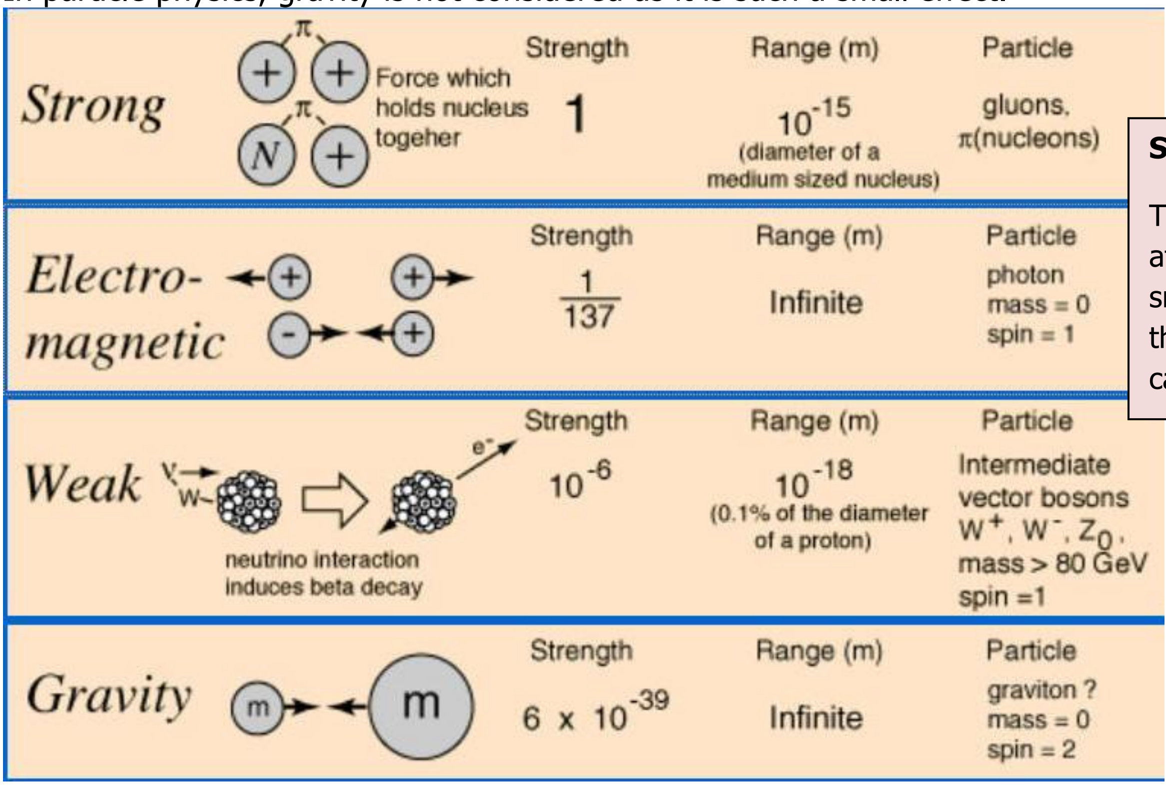
Complete the above checklist with the notes of each section before you attempt to answer any questions on this section of work.

Fundamental Forces

There are 4 fundamental forces in the Universe; every other force is based off these. These are, in order of strength, strong, electromagnetic, weak and gravity.

Einstein has theorised that gravity is not actual a force; however, this still an area of active research in Physics.

In particle physics, gravity is not considered as it is such a small effect.

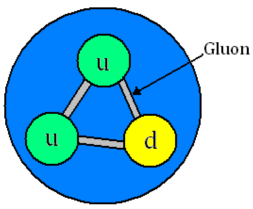


Study Tip

The gravitational attraction is so small compared to the other forces, it can be ignored.

The Strong Interaction

The strong nuclear force acts between composed of smaller particles called quarks.
A particle made from quarks is called a **HADRON.**
Protons and neutrons are examples of hadrons.
Since Hadrons are the only particles made of quarks only they experience the strong nuclear force.



The strong nuclear force can also be called the strong interaction.

This is the force responsible for producing an atomic nucleus.

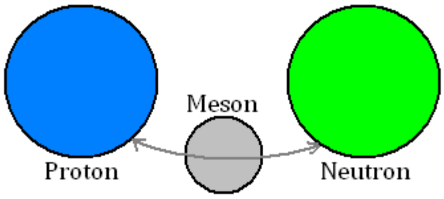
It is the strongest force in the Universe (as the name suggests).

Hadrons can be divided into 2 smaller categories.

Those made out of three quarks, **BARYONS. Protons and neutrons are examples of baryons.**

Those made out of two quarks, **MESONS.**

In all hadrons, the quarks are attracted to each other by exchanging virtual particles called 'gluons'.



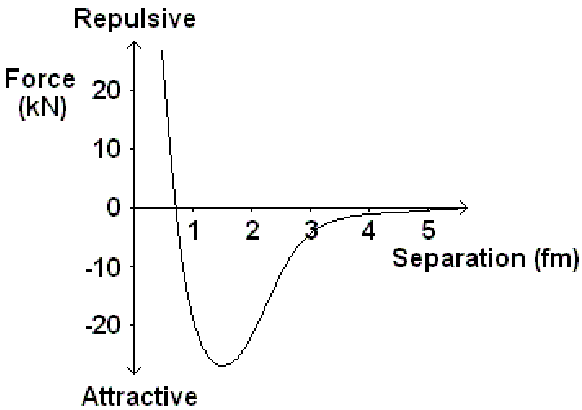
Force mechanisms work by transferring virtual particles between the particles called virtual particles.

The strong force virtual particle is called the gluon.
Each fundamental force has its own virtual particle – this gives the force its properties.

For example, electromagnetism is infinite in range as the photon is infinite in range.

On a larger scale the strong nuclear force acts between the hadrons themselves, keeping them together.
At the quark level, we say that a pion (п) is exchanged between the hadrons, this is the same as the gluon it is just named something else.
This is called the residual strong nuclear force as the force truly acts on the quark level.

Force Graphs
Neutron-Neutron or Neutron-Proton
Here is the graph of how the force varies between two neutrons or a proton and a neutron as the distance between them is increased.



The strong force can cause repulsion or attraction between two hadrons depending on the hadron separation.

The strong force does not affect any particle without quarks i.e. leptons.

The strong force has a very small range however.

We can see that the force is very strongly repulsive at separations of less than 0.7 fm (x 10^{-15} m). **This prevents all the nucleons from crushing into each other.** This allows protons and neutrons to exist.
This is why the strong force does not crush all matter made from quarks together and the nucleus exists.

Above this separation the force is strongly attractive with a peak around 1.3 fm. When the nucleons are separated by more than 5 fm they no longer experience the strong force.
This allows the nucleus to form, but also explains why nuclei do not form as extremely large pieces of matter – they are limited in size to the range of the strong force.

Study Tip

Femto is a prefix meaning 10^{-15}.

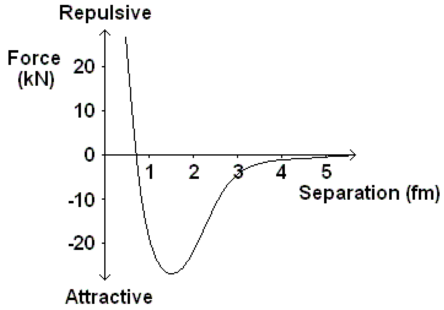
This is used for lengths on the scale of quarks.

Study Tip

The range of the strong nuclear force is only a few femtometres. It struggles to hold together very large nuclei, which makes them unstable.

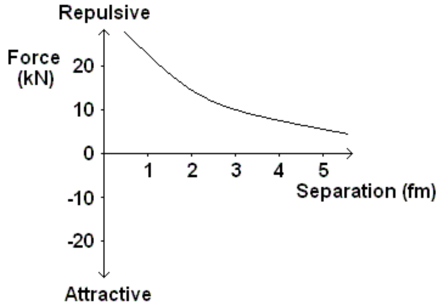
Proton-Proton

The force-separation graphs for two protons is different. They both attract each other due to the strong force but they also repel each other due to the electromagnetic force which causes two like charges to repel.



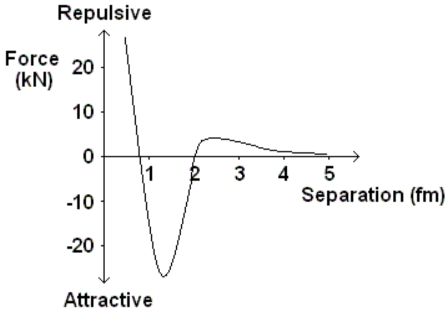
Graph A

Graph **A** shows how the strong nuclear force varies with the separation of the protons



Graph B

Graph **B** shows how the electromagnetic force varies with the separation of the protons



Graph C

Graph **C** shows the resultant of these two forces: repulsive at separations less than 0.7 fm, attractive up to 2 fm when the force becomes repulsive again.

Physics Tip

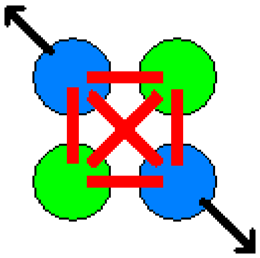
The range of the strong nuclear force is only a few femtometres.

It struggles to hold together very large nuclei, this makes large nuclei unstable.

Neutrons – Nuclear Cement

In the lighter elements, the number of protons and neutrons in the nucleus is the same. As the nucleus gets bigger more neutrons are needed to keep it together.

Adding another proton means that all the other nucleons feel the strong force attraction.
It also means that all the other protons feel the electromagnetic repulsion.

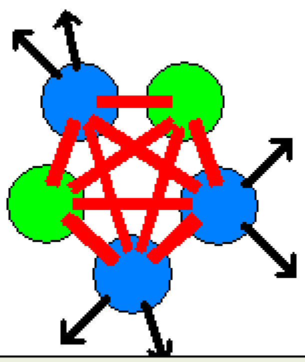


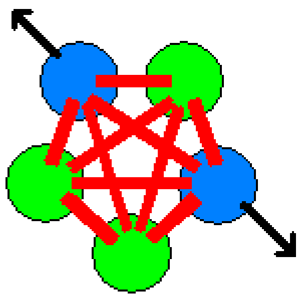
A stable nucleus contains particles which exert a much greater strong force attraction than electromagnetic repulsion.

An unstable nucleus contains particles which exert a similar sized strong force attraction and electromagnetic repulsion.

If the electromagnetic force was greater than strong force attraction, the nucleus could not form.

Adding another neutron adds to the strong force attraction between the nucleons but, since it is uncharged, it does not contribute to the electromagnetic repulsion.





As neutrons only interact via the strong force, they increase the stability of the nucleus.

However, **extremely neutron-rich nuclei do not exist in the Universe**, since other quantum mechanical effects mean too many neutrons would cause the nucleus to fission or simply decay via the beta decay process.

A large nucleus needs many more neutrons than protons as the strong force has a limited range compared to electromagnetic repulsion, this means that neutrons at either end of a large nucleus do not attract each other.

To compensate for this, more neutrons are placed inside the nucleus.

Increasing the neutrons increases stability as it increases the presence of the strong force (which is stronger than the electromagnetic force) and does not increase the presence of the electromagnetic force.

Leptons

Any particle which is fundamental, cannot be broken down further, so is not made from quarks is called a **LEPTON.**

As leptons are not made from quarks, they can not act via the strong force, only the weak and electromagnetic force.

If a decay involves leptons, it can not be caused by the strong force, only the weak (as electromagnetic interactions do not cause decays).

Examination Tip

It is a common examination question to be asked to 'Describe the interaction that is responsible for keeping protons and neutrons together in a stable nucleus.'

the strong interaction (1 mark)

has short range OR mention range (less than 5 fm) (1 mark)

attraction up to 5 fm (1 mark)

repulsive (any distance below 1fm) (1 mark)

is zero/negligible beyond 5 fm (1 mark)

Alpha Decay

Prior Knowledge Link
This is a topic found in a previous GCSE module **- Radioactivity**

When a nucleus decays in this way an alpha particle (a helium nucleus) is ejected from the nucleus.

$$^{A}_{Z}X \rightarrow ^{A-4}_{Z-2}Y + ^{4}_{2}\alpha \quad \text{or} \quad ^{A}_{Z}X \rightarrow ^{A-4}_{Z-2}Y + ^{4}_{2}He$$

You must remember the alpha decay nuclear equation.

Physics Tip

An alpha particle is a fast-moving helium nucleus emitted from the nucleus of another atom.

All the emitted alpha particles travelled at the same speed, meaning they had the same amount of kinetic energy.

The law of conservation of mass-energy is met, the energy of the nucleus before the decay is the same as the energy of the nucleus and alpha particle after the decay.

Alpha decay is NOT due to the weak interaction but Beta decay IS.
Alpha decay occurs via the weak interaction as only matter made from quarks are involved in it.

Examination Tip

It is a common examination question to ask why alpha decay does not occur via the weak interaction.

Alpha decay occurs via the strong interaction (1 mark)

This is because no leptons are involved in alpha decay (1 mark).

No particle flavour/ neutrino is produced (1 mark)

This means the decay happens quickly and produces particles of identical energy (1 mark).

Beta Decay and the Neutrino

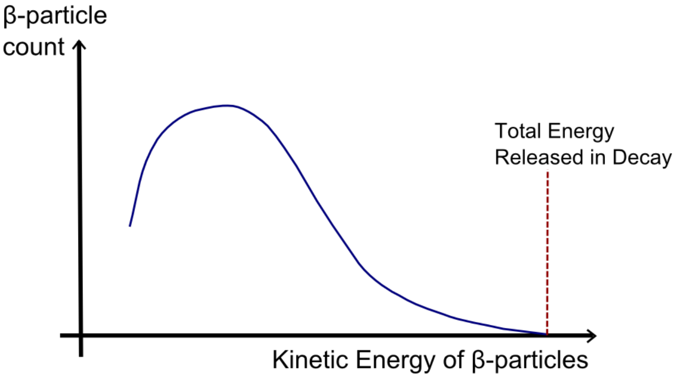
Prior Knowledge Link
This is a topic found in a previous GCSE module **- Radioactivity**

In beta decay a neutron in the nucleus changes to a proton and releases a beta particle (an electron).

Physics Tip

A beta minus particle is a fast-moving electron emitted from the nucleus of another atom.

The problem with beta decay was that the electrons had a range of energies, so it appeared the law of conservation of mass-energy is violated, energy seems to disappear.



This graph shows that different beta particles are produced with a different range of kinetic energies.

This would violate the energy-mass conversation law if it was the only particle produced in the decay.

To ensure this violation does not occur, there must be another particle being made with zero mass but variable speeds, the neutrino. This particle must take some of the kinetic energy.
So, the energy does not disappear out of the Universe, it is lost as the kinetic energy of the neutrinos, as the neutrinos leave with different kinetic energies, the beta particles have different energies (so the total energy before is the same as the total energy after the decay – energy is conserved).

Study Tip

Make sure you do not forget the anti-neutrino in the beta minus decay and the neutrino in the beta plus decay. It can be easily missed as it does not change the nucleon or proton number.

In fact, there are two types of beta decay.

The beta decay covered at GCSE, it actually called the beta minus decay.

Beta Minus (β^-) Decay
In neutron-rich nuclei a neutron may decay into a proton, electron and an anti-electron neutrino.

$$n \rightarrow p + e^- + \overline{\nu_e}$$

Examination Tip

It is a common examination question to ask which fundamental force is responsible for beta decay…

It is the weak interaction/weak nuclear force (1 mark).

Because it involves leptons and hadrons/ because quark (1 mark).

Whilst the character/flavour/identity/type is changed (1 mark).

Beta Plus (β^+) Decay
In proton-rich nuclei a proton may decay into a neutron, positron and an electron neutrino.

$$p \rightarrow n + e^+ + \nu_e$$

Physics Tip

A beta plus particle is a fast-moving positron emitted from the nucleus of another atom.

Physics Tip

Make sure you do not forget the anti-neutrino (or neutrino) in the beta decay equations.

It can be easily missed because it does not change the nucleon or the proton numbers.

Examination Tip

It is a common examination question to ask how we can identify that a beta decay is occurring…

Electron released (from nucleus) which is observed in a cloud chamber. (1 mark)

Antineutrino/neutrino released (1 mark)

No photon released (no energy is given out) (1 mark)

Examination Tip

It is a common examination question to recognise and state the beta decay.

Do not forget the corresponding neutrino or anti-neutrino depending on the beta decay.

Examination Tip

It is a common examination question to be asked to 'State two differences between the parent nucleus and the daughter nucleus after electron capture'.

The daughter nucleus has 1 more neutron than the parent nucleus (1 mark).

The parent nucleus has 1 less proton than the daughter nucleus (1 mark).

Examination Tip

It is a common examination question to be asked look at beta decay.

When scientists studied beta decay they observed that

- the beta particle and the daughter nucleus did not travel in opposite directions
- beta particles from the decay of a particular nuclide had a range of energies.

‘Explain how these observations led to the prediction of a previously undiscovered particle.’

This can be answered as following….

Conservation of momentum or energy discussed (1 mark)

Third particle carries some energy or momentum (1 mark)

Each decay (of a given nuclide) has the same energy (1 mark)

Mention of components of momentum (perpendicular to direction of recoil) (1 mark)

VIDEO

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REVISION SHEET

Highlight or underline the key information on the revision sheet to consolidate your understanding.

The *Strong Nuclear Force* Binds Nucleons Together

There are several different **forces** acting on the nucleons in a nucleus. The two you already know about are **electrostatic** forces from the protons' electric charges, and **gravitational** forces due to the masses of the particles.

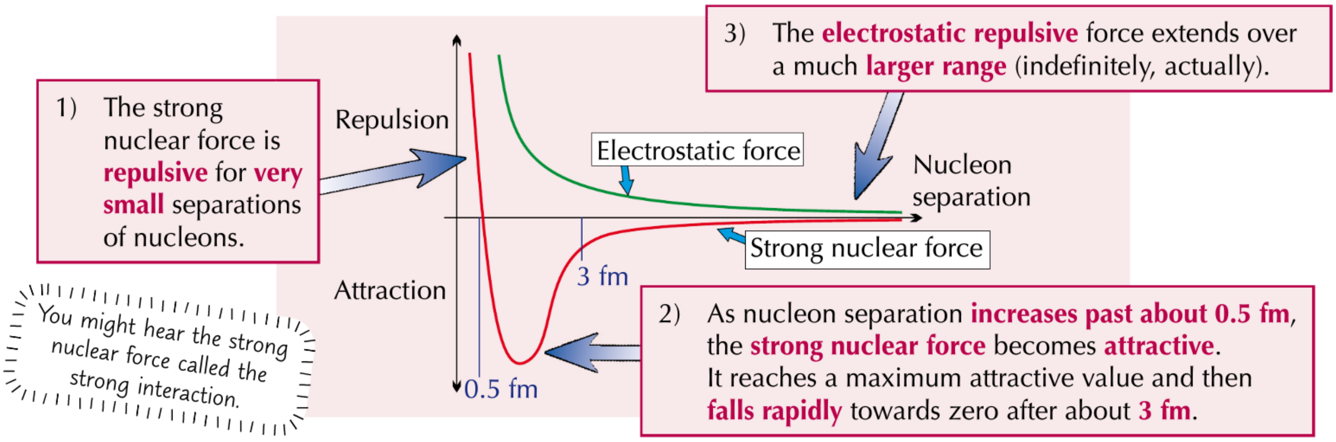
If you do the calculations (don't worry, *you* don't have to) you find the repulsion from the **electrostatic force** is much, much **bigger** than the **gravitational** attraction. If these were the only forces acting in the nucleus, the nucleons would **fly apart**. So there must be **another attractive force** that **holds the nucleus together** — called the **strong nuclear force**.
(The gravitational force is so small, you can just ignore it.)

The **strong nuclear force** is quite **complicated**:

1) To **hold the nucleus together**, it must be an **attractive force** that's **stronger** than the electrostatic force.
2) Experiments have shown that the strong nuclear force has a **very short range**. It can only hold nucleons together when they're separated by up to **a few femtometres** (1 fm = 1×10^{-15} m) — the size of a nucleus.
3) The **strength** of the strong nuclear force **quickly falls** beyond this distance (see the graph below).
4) Experiments also show that the strong nuclear force **works equally between all nucleons**. This means that the size of the force is the same whether it's proton-proton, neutron-neutron or proton-neutron.
5) At **very small separations**, the strong nuclear force must be **repulsive** or it would **crush** the nucleus to a **point**.

The *Size* of the Strong Nuclear Force *Varies* with *Nucleon Separation*

The **strong nuclear force** can be plotted on a **graph** to show how it changes with the **distance of separation** between **nucleons**. If the **electrostatic force** is also plotted, you can see the **relationship** between these **two forces**.



α *Emission* Happens in *Very Big Nuclei*

1) **Alpha emission** only happens in **very big** nuclei, like **uranium** and **radium**.
2) The **nuclei** of these atoms are just **too massive** for the strong nuclear force to keep them stable.
3) When an alpha particle is **emitted**:

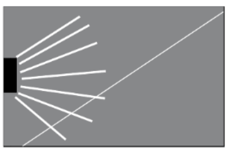
$$^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}\alpha$$

nucleon number decreases by 4

proton number decreases by 2

The **proton number decreases** by **two**, and the **nucleon number decreases** by **four**.

Alpha particles have a very **short range** — only a few cm in air. This can be seen by observing the tracks left by alpha particles in a **cloud chamber**. You could also use a **Geiger counter** (a device that measures the amount of ionising radiation). Bring it up close to the alpha source, then **move it away** slowly and observe how the **count rate drops**.



The thin line is a cosmic ray particle

β^- Emission Happens in Neutron-Rich Nuclei

1) **Beta-minus** (usually just called beta) decay is the emission of an **electron** from the **nucleus** along with an **antineutrino**.
2) Beta decay happens in isotopes that are unstable due to being **'neutron rich'** (i.e. they have too many more **neutrons** than **protons** in their nucleus).
3) When a nucleus ejects a beta particle, one of the **neutrons** in the nucleus is **changed** into a **proton**.

The **proton number increases** by **one**, and the **nucleon number stays the same**.

Beta particles have a much greater range than alpha particles.

nucleon number stays the same

$$^{187}_{75}Re \longrightarrow \, ^{187}_{76}Os + \, ^{0}_{-1}\beta + \bar{\nu}_e$$

proton number increases by 1

In beta decay, you get a **tiny neutral particle** called an **antineutrino** released. This antineutrino carries away some **energy** and **momentum**.

Neutrinos Were First *Hypothesised* Due to Observations of *Beta Decay*

1) Scientists originally thought that the **only** particle emitted from the nucleus during beta decay was an **electron**.
2) However, observations showed that the **energy** of the particles **after** the **beta decay** was **less** than it was **before**, which didn't fit with the principle of **conservation of energy** (p. 64).
3) In 1930 Wolfgang Pauli suggested **another particle** was being emitted too, and it carried away the **missing energy**. This particle had to be **neutral** (or charge wouldn't be **conserved** in beta decay) and had to have **zero** or **almost zero** mass (as it had never been **detected**).
4) Other discoveries led to Pauli's theory becoming accepted and the particle was named the **neutrino**. (We now know this particle was an antineutrino — p. 6).
5) The neutrino was eventually observed 25 years later, providing evidence for Pauli's hypothesis.

Credit: CGP Revision Guide Editions

REVIEW QUESTIONS

To assess your understanding, answer the following questions on this topic.

A4. The strong force binds the nucleus together. Explain why the force must be repulsive at very short distances.

[1 Mark]

....

....

A5. The strong force binds the nucleus together. Explain why a nucleus containing two protons is unstable, but one containing two protons and two neutrons is stable.

[1 Mark]

....

....

The answers to the review questions are found on the next page.

REVIEW ANSWERS

A4. The strong force binds the nucleus together. Explain why the force must be repulsive at very short distances.

[1 Mark]

The strong nuclear force must be repulsive at very small nucleon separations to prevent the nucleus being crushed to a point.

A5. The strong force binds the nucleus together. Explain why a nucleus containing two protons is unstable, but one containing two protons and two neutrons is stable.

[1 Mark]

The protons repel each other with an electrostatic force and attract each other with the nuclear strong force. The strong force is not large enough to overcome this repulsion.
When two neutrons are added to the nucleus, they attract each other and the protons via the strong force. The strong force is now able to balance out the force of repulsion between the protons.

SELF ASSESSMENT

To practice your understanding, answer the following questions.

DO NOT WORRY IF YOU STRUGGLE AT FIRST.

The answers are found after the questions.

A1. Name the constituent of an atom which

A1.1 has zero charge,

[1 Mark]

....

....

A1.2 has the largest charge to mass ratio,

[1 Mark]

....

....

A1.3 when removed leaves a different isotope of the element.

[1 Mark]

....

....

An α particle is the same as a nucleus of helium, $^{4}_{2}He$.

The equation

$$^{229}_{90}Th \longrightarrow {}^{X}_{Y}Ra + \alpha$$

represents the decay of thorium by the emission of an α particle.

Determine

A1.4 the values of **X** and **Y**, shown in the equation,

[1 Mark]

X = ...

Y = ...

A1.5 the ratio $\frac{\text{mass of } {}^{X}_{Y}\text{Ra nucleus}}{\text{mass of } \alpha \text{ particle}}$

[2 Marks]

....

....

....

Reference: AQA A Level Physics Legacy A Examinations

A2.1 Determine the charge, in C, of a ${}^{239}_{92}\text{U}$ nucleus.

[1 Mark]

....

....

A2.2 A positive ion with a ${}^{239}_{92}\text{U}$ nucleus has a charge of 4.80×10^{-19} C.
Determine how many electrons are in this ion.

[3 Marks]

....

....

....

....

A2.3 A ${}^{239}_{92}\text{U}$ nucleus may decay by emitting **two** β^- particles to form a plutonium nucleus ${}^{X}_{Y}\text{Pu}$. State what **X** and **Y** represent and give the numerical value of each.

[4 Marks]

X

....

....

Y

....

....

Reference: AQA A Level Physics Legacy A Examinations

ANSWERS

A1.1 neutron **(1)**

A1.2 electron **(1)**

A1.3 neutron **(1)**

3

A1.5 (X =) 225 **(1)**

(Y =) 88 **(1)**

A1.6 $\left(\frac{\text{mass of } ^{225}_{88}\text{Ra}}{\text{mass of } \alpha \text{ particle}} = \frac{225}{4}\right)$ = 56(.3) **(1)**

3

[6]

A2.1 (charge) = 92 × 1.60 × 10^{-19} = 1.47 × 10^{-17} (C) **(1)**

A2.2 ((magnitude of ion charge) = 3(*e*) **(1)**
number of electrons (= 92 – 3) = 89 **(1)**

4

A2.3 (X: number of nucleons [or number of neutrons plus protons or mass number] **(1)**
239 **(1)**
Y: number of protons [or atomic number] **(1)**
94 **(1)**

4

[8]

ASSESSMENT QUESTION

Please answer this assessment question on this topic in Physics.

This work will be formally assessed with feedback given.

This work will be submitted at the start of the A-Level course in Year 12.

If we require any help or you wish to receive immediate feedback, please e-mail Mr. Turnbull.

A3. A neutral atom of a radium isotope may be represented by $^{228}_{88}\text{Ra}$.

A3.1 Name the constituents of this atom and state how many of each are present.

[3 Marks]

....

....

....

....

A3.2 Which constituent of an atom has the largest specific charge?

[1 Mark]

....

....

A3.3 This isotope of radium decays by β^- decay to form an element with symbol, Ac.

Write down an equation that represents this decay.

[4 Marks]

....

....

....

....

A3.4 $^{A}_{Z}\text{Ra}$ is a neutral atom of a different isotope of radium. State a possible value for **A** and for **Z**.

[2 Marks]

A: ....

Z: ....

Reference: AQA A Level Physics June 2012 Examination Unit 1

TOPIC: 3.2.1.4: Particle Interactions
SPEC CHECK

Specification	Completed?
Four fundamental interactions: gravity, electromagnetic, weak nuclear, strong nuclear. (The strong nuclear force may be referred to as the strong interaction.)	
The concept of exchange particles to explain forces between elementary particles.	
The electromagnetic force; virtual photons as the exchange particle.	
The weak interaction limited to $\beta-$and $\beta+$ decay, electron capture and electron–proton collisions; $W+$ and $W-$ as the exchange particles.	
Simple diagrams to represent the above reactions or interactions in terms of incoming and outgoing particles and exchange particles.	

Student Checklist
Complete the following before attempting any work on this section.

Have I…….	**Yes or No?**
Read through the notes of this section?	
Highlighted/underlined the key concepts of this section?	
Made my own notes based on the notes of this section?	
Brought the notes to be used in lesson?	

Complete the above checklist with the notes of each section before you attempt to answer any questions on this section of work.

The Four Interactions

There are four forces in the universe, some you will have come across already and some will be new:

The electromagnetic interaction causes an attractive or repulsive force between charges.
The gravitational interaction causes an attractive force between masses.
The strong nuclear interaction causes an attractive (or repulsive) force between quarks (hadrons).
The weak nuclear interaction does not cause a physical force, it makes particles decay. All particles experience the weak force.
'Weak' means there is a low probability that it will happen.

Interaction/Force	Range	Relative Strength	
Strong Nuclear	$\sim 10^{-15}$m	1	(1)
Electromagnetic	∞	$\sim 10^{-2}$	(0.01)
Weak Nuclear	$\sim 10^{-18}$m	$\sim 10^{-7}$	(0.0000001)
Gravitational	∞	$\sim 10^{-36}$	(0.000000000000000000000000000000000001)

The properties of a force interaction are given by the properties of its exchange particle.

Exchange Particles

In 1935 Japanese physicist Hideki Yukawa put forward the idea that the interactions/forces between two particles were caused by 'virtual particles' being exchanged between the two particles.

He was working on the strong nuclear force which keeps protons and neutrons together and theorised that they were exchanging a particle back and forth that 'carried' the force and kept them together. This is true of all the fundamental interactions.
These exchange particles only exist for a very, short period of time.

The general term for exchange particles is *bosons* and they are fundamental particles like quarks and leptons.

Ice Skating Analogy

Imagine two people on ice skates that will represent the two bodies experiencing a force.

If A throws a bowling ball to B, A slides back when they release it and B moves back when they catch it. Repeatedly throwing the ball back and forth moves A and B away from each other, the force causes repulsion.

The analogy falls a little short when thinking of attraction.

Imagine that A and B are exchanging a boomerang (bear with it), throwing it behind them pushes A towards B, B catches it from behind and moves towards A. The force causes attraction.

Study Tip

The virtual photon passed between particles can cause them to repel or attract.

Which Particle for What Force

Each of the interactions/forces has its own exchange particles.

<table>
<tr><th>Interaction/Force</th><th colspan="3">Exchange Particle</th><th>What is acts upon</th></tr>
<tr><td>Strong Nuclear</td><td>Gluons (name when between quarks)</td><td colspan="2">Pions (name when between Baryons)</td><td>Nucleons (Hadrons)</td></tr>
<tr><td>Electromagnetic</td><td colspan="3">Virtual Photon</td><td>Charged particles</td></tr>
<tr><td>Weak Nuclear</td><td>W^+</td><td>W^-</td><td>Z^0</td><td>All particles</td></tr>
<tr><td>Gravitational</td><td colspan="3">Graviton</td><td>Particles with masses</td></tr>
</table>

When you are discussing quarks, it is best to say the exchange particle is the gluon. When discussing protons and neutrons, it is best to say the exchange particle is the pion. It is the same particle, just called different names.

Borrowing Energy to Make Particles

The exchange particles are made from 'borrowed' energy, borrowed from where? From nowhere! Yukawa used the Heisenberg Uncertainty Principle to establish that a particle of mass-energy ΔE could exist for a time Δt if $\boxed{\Delta E . \Delta t \leq h}$ where h is Planck's constant.

This means that a heavy particle can only exist for a short time while a lighter particle may exist for longer.

h is Planck's Constant, h = 6.63 x 10^{-34} J s.

The W/Z and pion boson have a rest mass, this means the force they produce has a finite range. The photon and graviton have no rest mass, this means the force has an infinite range.

In 1947 the exchange particle of the strong nuclear interaction was observed in a cloud chamber. By 2017, the only exchange particle which has not been observed is the graviton. This could either be because gravity is very weak or gravity is not actually a force.

Lending Money Analogy

Think of making exchange particles in terms of lending somebody some money.

If you lend somebody £50 you would want it paid back soon.

If you lend somebody 50p you would let them have it for longer before paying you back.

Study Tip

The fourth fundamental interaction is gravity. Particle physicists never both about gravity because it is so incredibly feeble compared with the other types of interaction. Gravity only matters when you have big masses like stars and planets.

It is not known for certain what the exchange particle of gravity is, but it is believed to be the graviton (which has not been observed yet).

Feynman Diagrams

American Physicist called Richard Feynman came up with a way of visualising forces and exchange particles. Below are some examples of how Feynman diagrams can represent particle interactions.

The most important things to note when dealing with Feynman diagrams are the arrows and the exchange particles, the lines do not show us the path that the particles take only which come in and which go out.

The arrows tell us which particles are present before the interaction and which are present after the interaction.

The wave represents the interaction taking place with the appropriate exchange particle labelled.

The particles at the bottom of the diagram represent the particles before the interaction.

The particles at the top of the diagram represent the particles after the interaction.

The angle of the lines is irrelevant. This is not the movement of the particles.

You can only join lines with arrows if you include a 'wavy line' of the exchange particle.

It is possible to represent an anti-particle with particle notation with the arrow moving in the opposite direction.

Two 'wavy lines' can never be joined to each other.

Study Tip

When drawing particle interaction diagrams, the incoming particles start from the bottom and move upwards.

Examples

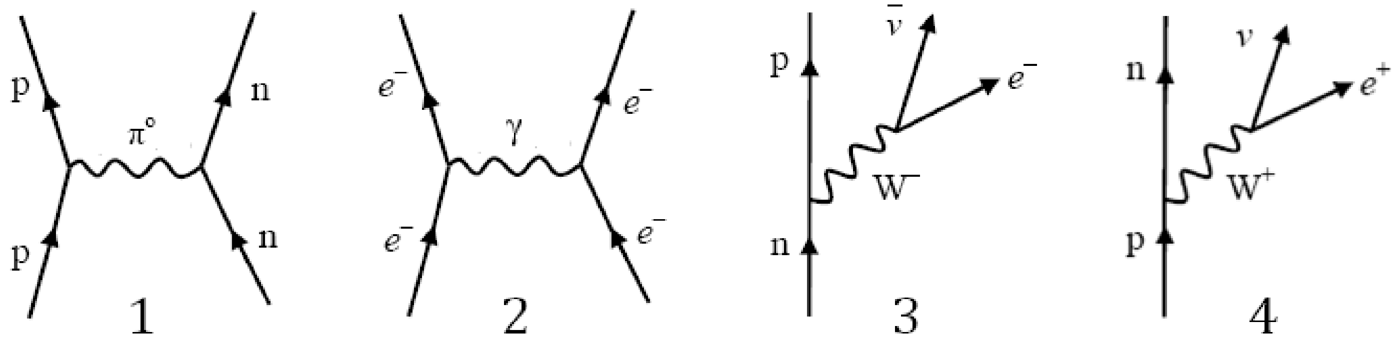


Diagram 1 represents the strong interaction. A proton and neutron are attracted together by the exchange of a neutral pion.

Diagram 2 represents the electromagnetic interaction. Two electrons repel each other by the exchange of a virtual photon.

Diagram 3 represents beta minus decay. A neutron decays due to the weak interaction into a proton, an electron and an anti-electron neutrino

Diagram 4 represents beta plus decay. A proton decays into a neutron, a positron and an electron neutrino.

Study Tip

Electron capture and electron-proton collisions are confusingly similar. They have different particle interaction diagrams and use different W bosons because the boson comes from the particle that is 'acting'.

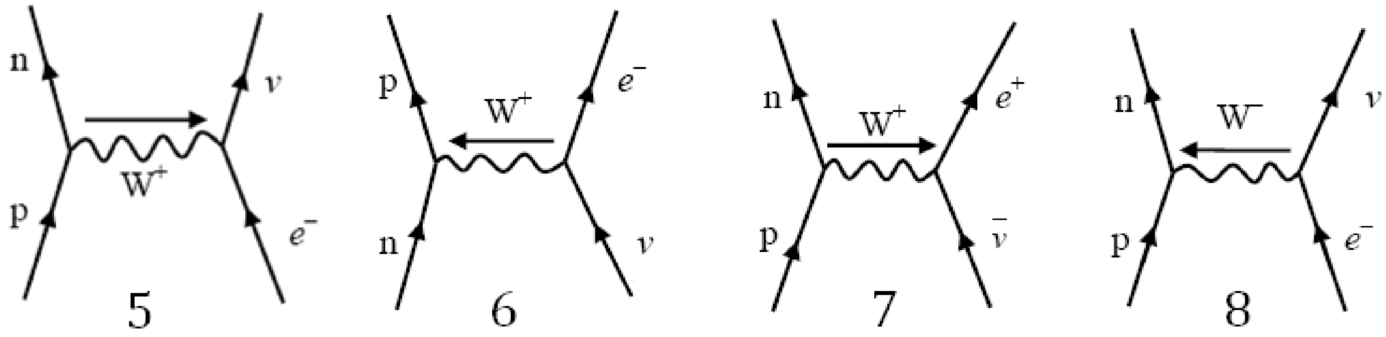


Diagram 5 represents electron capture. A proton captures an electron and becomes a neutron and an electron neutrino.

Diagram 6 represents a neutrino-neutron collision. A neutron absorbs a neutrino and forms a proton and an electron.

Diagram 7 represents an antineutrino-proton collision. A proton absorbs an antineutrino and emits a neutron and an electron.

Diagram 8 represents an electron-proton collision. They collide and emit a neutron and an electron neutrino.

Getting the Exchange Particle
The aspect of Feynman diagrams that students often struggle with is labelling the exchange particle and the direction to draw it.

Look at what you start with:

If it is positive and becomes neutral, you can think of it as throwing away its positive charge so the W boson will be positive. This is the case in electron capture.

If it is positive and becomes neutral, you can think of it as gaining negative to neutralise it so the W boson will be negative. This is the case in electron-proton collisions.

If it is neutral and becomes positive, we can think of it either as gaining positive (W+ boson) or losing negative (W– boson in the opposite direction).
Work out where the charge is going and label it.

Examination Tip

Feynman diagrams can be drawn in terms of particles or quarks.

It is more common that the examination question will show a Feynman diagram in terms of quarks.

Examination questions then ask you to identify particles based on quark composition.

Examination Tip

It is a common examination question to be asked to ‘describe how the variation of the strong nuclear force with distance contributes to the stability of the nucleus’.

(Short-range) attraction up to about 3 fm (1 mark)

(Very short-range) repulsion closer than 0.5 fm (1 mark)

Prevent proton and neutron moving closer or further apart (1 mark)

VIDEO

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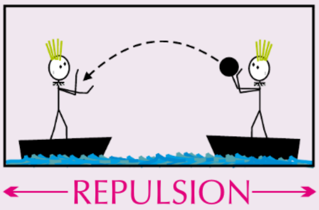
REVISION SHEET

Highlight or underline the key information on the revision sheet to consolidate your understanding.

Forces *are Caused by* ***Particle Exchange***

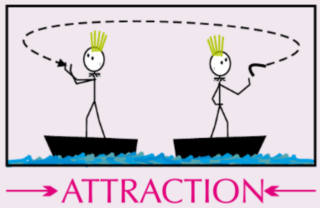
You can't have **instantaneous action at a distance** (according to Einstein, anyway). So, when two particles **interact**, something must **happen** to let one particle know that the other one's there. That's the idea behind **exchange particles**.

1) **Repulsion —** Each time the **ball** is **thrown or caught** the people get **pushed apart**. It happens because the ball carries **momentum**.



Particle exchange also explains **attraction**, but you need a bit more imagination.

2) **Attraction —** Each time the **boomerang** is **thrown or caught** the people **get pushed together**. (In real life, you'd probably fall in first.)



These exchange particles are called **gauge bosons**.

The **repulsion** between two **protons** is caused by the **exchange** of **virtual photons**, which are the gauge bosons of the **electromagnetic** force. Gauge bosons are **virtual** particles — they only exist for a **very short time**.

There are ***Four Fundamental Forces***

All forces in nature are caused by four **fundamental** forces — the strong nuclear force, the weak nuclear force, the electromagnetic force and gravity. Each one has its **own gauge boson** and these are the ones you have to learn:

Type of Interaction	Gauge Boson	Particles Affected
electromagnetic	virtual photon (symbol, γ)	charged particles only
weak	W^+, W^-	all types
strong	pions (π^+, π^-, π^0)	hadrons only

Particle physicists never **bother** about **gravity** because it's so incredibly **feeble** compared with the other types of interaction. Gravity only really **matters** when you've got **big masses** like **stars and planets**.

In the **strong nuclear force**, pions are described as being exchanged between **nucleons**. You might also see it described as **gluons** being exchanged between **quarks** (p. 13).

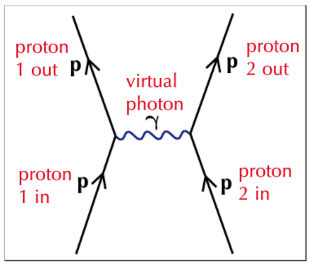
The ***Larger*** *the* ***Mass*** *of the* ***Gauge Boson****, the* ***Shorter*** *the* ***Range*** *of the* ***Force***

1) The **W bosons** have a **mass** of about **100 times that of a proton**, which gives the weak force a **very short range**. Creating a **virtual W particle** uses **so much energy** that it can only exist for a **very short time** and it **can't travel far**.
2) On the other hand, the **photon** has **zero mass**, which gives you a force with **infinite range**.

You can use ***Diagrams*** *to Show What's* ***Going In*** *and What's* ***Coming Out***

Particle interactions can be hard to get your head around. A **neat way** of **solving problems** is by **drawing simple diagrams** of particle interactions rather than doing **calculations**.

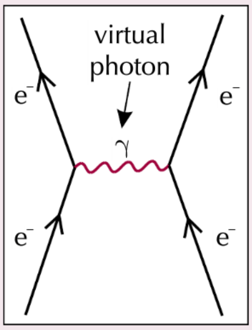
1) **Gauge bosons** are represented by **wiggly lines** (technical term).
2) Other **particles** are represented by **straight lines**.



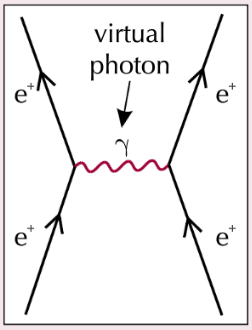
*You Need to Be Able to **Draw Diagrams** of these **Interactions***

Electromagnetic Repulsion

This is the easiest of the lot. When two particles with **equal charges** get close to each other, they **repel**.



two electrons repelling each other



two positrons repelling each other

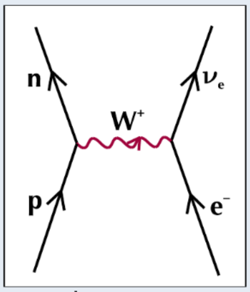
RULES FOR DRAWING PARTICLE INTERACTION DIAGRAMS:

1) **Incoming** particles start at the bottom of the diagram and move upwards.
2) The **baryons** (p.10) and **leptons** (p.12) can't cross from one side to the other.
3) Make sure the charges on both sides balance. The **W** bosons carry **charge** from one side of the diagram to the other.
4) A **W⁻** particle going to the **left** has the same effect as a **W⁺** particle going to the **right**.

Electron Capture and Electron-proton Collisions

Electrons and protons are of course attracted by the **electromagnetic interaction** between them, but if a proton **captures** an electron, the **weak interaction** can make this interaction happen.

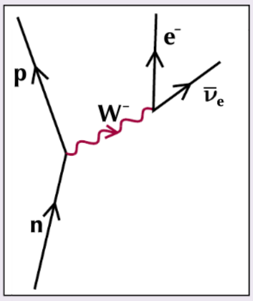
$$p + e^- \rightarrow n + \nu_e$$



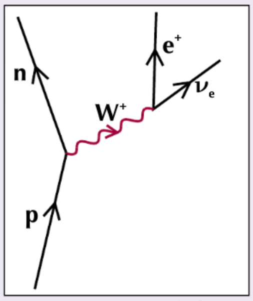
electron capture

You also need to know about **electron-proton collisions**, where an electron **collides** with a proton. The equation is just the same as electron capture but in the diagram a **W⁻ boson** goes from the **electron** to the **proton** instead of a W⁺ travelling the other way.

Beta-plus and Beta-minus Decay



β^- decay



β^+ decay

$$n \rightarrow p + e^- + \bar{\nu}_e$$

$$p \rightarrow n + e^+ + \nu_e$$

You get an **antineutrino** in β^- decay and a **neutrino** in β^+ decay so that **lepton number** (p.12) is conserved.

You'll see on p.14 that when a proton changes to a neutron or vice versa, it has to be the weak interaction.

Credit: CGP Revision Guide Editions

REVIEW QUESTIONS

To assess your understanding, answer the following questions on this topic.

A7. List the four fundamental forces in nature.

[1 Mark]

....

....

....

....

A8. Explain what a virtual particle is.

[1 Mark]

....

....

The answers to the review questions are found on the next page.

REVIEW ANSWERS

A7. List the four fundamental forces in nature.

[1 Mark]

Strong Nuclear
Weak
Electromagnetic
Gravitational

A8. Explain what a virtual particle is.

[1 Mark]

A virtual particle is a particle which only exists for a short period of time to exchange a force interaction between particles.

SELF ASSESSMENT

To practice your understanding, answer the following questions.

DO NOT WORRY IF YOU STRUGGLE AT FIRST.

The answers are found after the questions.

A1.1 Give an example of an exchange particle other than a W^+ or W^- particle, and state the fundamental force involved when it is produced.

[2 Marks]

Exchange Particle ....

Fundamental Interaction ....

A1.2 State what roles exchange particles can play in an interaction.

[2 Marks]

....

....

Reference: AQA A Level Physics Legacy A Examinations

A2. The equation

$p \longrightarrow n + \beta^+ + \nu_e$

represents the emission of a positron from a proton.

A2.1 Draw the Feynman diagram that corresponds to the positron emission represented in the equation.

[4 Marks]

A2.2 Complete the following table using ticks ✓ and crosses ✗.

[4 Marks]

particle	**fundamental particle**	**meson**	**baryon**	**lepton**
p				
n				
β^+				
ν_e				

Reference: AQA A Level Physics Legacy A Examinations

ANSWERS

A1.1 Z^0 with the weak interaction
gluons or pions with the strong nuclear force
γ photons with electromagnetic interaction
gravitons with gravity
(any exchange particle **(1)** and corresponding interaction **(1)**)

A1.2 transfers energy
transfers momentum
transfers force
(sometimes) transfers charge any two **(1)(1)**

4

A2.1 Feynman diagram to show:
p changing to n **(1)**
W^+ **(1)**
β^+ and ν_e **(1)**
correct overall shape with arrows **(1)**

4

A2.2

particle	fundamental particle	meson	baryon	lepton
p		×	✓	×
n		×	✓	×
β^+	✓	×	×	✓
ν_e	✓	×	×	✓

(1) (1) (1) (1) (one for each correct line)

ASSESSMENT QUESTION

Please answer this assessment question on this topic in Physics.

This work will be formally assessed with feedback given.

This work will be submitted at the start of the A-Level course in Year 12.

If we require any help or you wish to receive immediate feedback, please e-mail Mr. Turnbull.

A3.1 State the role of **exchange particles** in the creation of forces between particles.

[1 Mark]

....

....

A3.2 Complete the table below to show an exchange particle that is responsible for each of the forces mentioned.

[3 Marks]

Interaction	**exchange particle responsible**
Weak nuclear force	
Strong force	
Electromagnetic force	

Reference: AQA A Level Physics January 2011 Unit 1 Examination

REVISION CHECKLIST

Specification reference	Checklist questions	
3.2.1.1	Can you represent a simple model of the atom, including the proton, neutron, and electron?	☐
3.2.1.1	Can you describe charge and mass of the proton, neutron, and electron in SI units and relative units?	☐
3.2.1.1	Can you explain the specific charge of the proton and the electron, and of nuclei and ions?	☐
3.2.1.1	Can you define and use 'proton number *Z*, nucleon number *A*' nuclide notation?	☐
3.2.1.1	Can you recognise and use the $^{A}_{Z}X$ notation?	☐
3.2.1.1	Can you define isotopes and use isotopic data?	☐
3.2.1.2	Can you explain the strong nuclear force and its role in keeping the nucleus stable?	☐
3.2.1.2	Can you describe short-range attraction up to approximately 3 fm and very-short range repulsion closer than approximately 0.5 fm?	☐
3.2.1.2	Can you describe unstable nuclei; alpha and beta decay?	☐
3.2.1.2	Can you use equations for alpha decay and β^- decay, including the need for the neutrino?	☐
3.2.1.2	Can you explain how the existence of the neutrino was hypothesised to account for conservation of energy in beta decay?	☐
3.2.1.3	Can you compare particle and antiparticle mass, charge, and rest energy in MeV?	☐

FURTHER READING

You may wish to read around the following topics to further extend your understanding ahead of the start of the course in Year 12.

The Classification of Particles (Leptons, Mesons and Baryons)

To watch a video looking at this concept, please scan one of the following codes with your smartphone.

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Quarks and Anti-Quarks

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DATASHEET

DATA - FUNDAMENTAL CONSTANTS AND VALUES

Quantity	Symbol	Value	Units
speed of light in vacuo	c	3.00×10^{8}	$\mathrm{m\,s^{-1}}$
permeability of free space	μ_0	$4\pi \times 10^{-7}$	$\mathrm{H\,m^{-1}}$
permittivity of free space	ε_0	8.85×10^{-12}	$\mathrm{F\,m^{-1}}$
magnitude of the charge of electron	e	1.60×10^{-19}	C
the Planck constant	h	6.63×10^{-34}	J s
gravitational constant	G	6.67×10^{-11}	$\mathrm{N\,m^{2}\,kg^{-2}}$
the Avogadro constant	N_A	6.02×10^{23}	$\mathrm{mol^{-1}}$
molar gas constant	R	8.31	$\mathrm{J\,K^{-1}\,mol^{-1}}$
the Boltzmann constant	k	1.38×10^{-23}	$\mathrm{J\,K^{-1}}$
the Stefan constant	σ	5.67×10^{-8}	$\mathrm{W\,m^{-2}\,K^{-4}}$
the Wien constant	α	2.90×10^{-3}	m K
electron rest mass (equivalent to 5.5×10^{-4} u)	m_e	9.11×10^{-31}	kg
electron charge/mass ratio	$\frac{e}{m_e}$	1.76×10^{11}	$\mathrm{C\,kg^{-1}}$
proton rest mass (equivalent to 1.00728 u)	m_p	$1.67(3) \times 10^{-27}$	kg
proton charge/mass ratio	$\frac{e}{m_p}$	9.58×10^{7}	$\mathrm{C\,kg^{-1}}$
neutron rest mass (equivalent to 1.00867 u)	m_n	$1.67(5) \times 10^{-27}$	kg
gravitational field strength	g	9.81	$\mathrm{N\,kg^{-1}}$
acceleration due to gravity	g	9.81	$\mathrm{m\,s^{-2}}$
atomic mass unit (1u is equivalent to 931.5 MeV)	u	1.661×10^{-27}	kg

ALGEBRAIC EQUATION

quadratic equation $x = \dfrac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

ASTRONOMICAL DATA

Body	Mass/kg	Mean radius/m
Sun	1.99×10^{30}	6.96×10^{8}
Earth	5.97×10^{24}	6.37×10^{6}

GEOMETRICAL EQUATIONS

arc length	$= r\theta$
circumference of circle	$= 2\pi r$
area of circle	$= \pi r^2$
curved surface area of cylinder	$= 2\pi rh$
area of sphere	$= 4\pi r^2$
volume of sphere	$= \frac{4}{3}\pi r^3$

Particle Physics

Class	Name	Symbol	Rest energy/MeV
photon	photon	γ	0
lepton	neutrino	ν_e	0
		ν_μ	0
	electron	$e^{\pm}$	0.510999
	muon	$\mu^{\pm}$	105.659
mesons	π meson	$\pi^{\pm}$	139.576
		π^0	134.972
	K meson	$K^{\pm}$	493.821
		K^0	497.762
baryons	proton	p	938.257
	neutron	n	939.551

Properties of quarks

antiquarks have opposite signs

Type	Charge	Baryon number	Strangeness
u	$+\frac{2}{3}e$	$+\frac{1}{3}$	0
d	$-\frac{1}{3}e$	$+\frac{1}{3}$	0
s	$-\frac{1}{3}e$	$+\frac{1}{3}$	-1

Properties of Leptons

		Lepton number
Particles:	e^-, ν_e ; μ^-, ν_μ	$+1$
Antiparticles:	e^+, $\overline{\nu_e}$, μ^+, $\overline{\nu_\mu}$	-1

Photons and energy levels

photon energy $E = hf = hc/\lambda$

photoelectricity $hf = \phi + E_{k\,(max)}$

energy levels $hf = E_1 - E_2$

de Broglie wavelength $\lambda = \frac{h}{p} = \frac{h}{mv}$

Waves

wave speed $c = f\lambda$ *period* $f = \frac{1}{T}$

first harmonic $f = \frac{1}{2l}\sqrt{\frac{T}{\mu}}$

fringe spacing $w = \frac{\lambda D}{s}$ *diffraction grating* $d \sin\theta = n\lambda$

refractive index of a substance s, $n = \frac{c}{c_s}$

for two different substances of refractive indices n_1 and n_2,

law of refraction $n_1 \sin\theta_1 = n_2 \sin\theta_2$

critical angle $\sin\theta_c = \frac{n_2}{n_1}$ for $n_1 > n_2$

Mechanics

moments moment $= Fd$

velocity and acceleration $v = \frac{\Delta s}{\Delta t}$ $a = \frac{\Delta v}{\Delta t}$

equations of motion $v = u + at$ $s = \left(\frac{u+v}{2}\right)t$

$v^2 = u^2 + 2as$ $s = ut + \frac{at^2}{2}$

force $F = ma$

force $F = \frac{\Delta(mv)}{\Delta t}$

impulse $F\,\Delta t = \Delta(mv)$

work, energy and power $W = F\,s\cos\theta$

$E_k = \frac{1}{2}m\,v^2$ $\Delta E_p = mg\Delta h$

$P = \frac{\Delta W}{\Delta t}$, $P = Fv$

$efficiency = \frac{useful\ output\ power}{input\ power}$

Materials

density $\rho = \frac{m}{V}$ *Hooke's law* $F = k\,\Delta L$

Young modulus $= \frac{tensile\ stress}{tensile\ strain}$ *tensile stress* $= \frac{F}{A}$

tensile strain $= \frac{\Delta L}{L}$

energy stored $E = \frac{1}{2}F\Delta L$

Acknowledgements

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This document has been produced for the AQA A Level Physics Specification.

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Only constructive and reasoned feedback will be considered.