Journey to the Centre of the Atom

Key Stage 4 Programme

Pupil Name	
Handbook Designed by	Dr. Liam Vormawah

Timetable and Assignment Submission

Timetable – Tutorials

1			
2			
3			
4			
5			
6 (Feedback)			

Timetable – Homework Assignments

Tutorial 1		
Tutorial 2		
Tutorial 3		
Tutorial 4		
Tutorial 5		

Assignment Submission – Lateness and Plagiarism

Lateness	
Submission after midnight on 9th August	10 marks deducted
Plagiarism	
Some plagiarism	10 marks deducted
Moderate plagiarism	20 marks deducted
Extreme plagiarism	Automatic fail

The Brilliant Club KS4 Programme – Pupil Feedback Report

Grade	Marks	What this means
1st	70+	Performing to an excellent standard at undergraduate level
2:1	60-69	Performing to a good standard at undergraduate level
2:2	50-59	Performing to an excellent standard at A-level
3rd	40-49	Performing to a good standard at A-level
Working towards a pass	0-39	Performing below a good standard at A-level
Did not submit	DNS	No assignment received by The Brilliant Club

Lateness	
Any lateness	10 marks deducted
Plagiarism	
Some plagiarism	10 marks deducted
Moderate plagiarism	20 marks deducted
Extreme plagiarism	Automatic fail

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

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

Learning Feedback Comment 1 - *Enter Key Learning Priority Here*	
What you did in relation to this Key Learning Priority *Enter feedback here*	How you could improve in the future *Enter feedback here*
Learning Feedback Comment 2 – *Enter Key Learning Priority Here*	
What you did in relation to this Key Learning Priority *Enter feedback here*	How you could improve in the future *Enter feedback here*
Learning Feedback Comment 3 – *Enter Key Learning Priority Here*	
What you did in relation to this Key Learning Priority *Enter feedback here*	How you could improve in the future *Enter feedback here*
Resilience Comment	
How you showed learning resilience during the course *Enter feedback here*	How you could build learning resilience in the future *Enter feedback here*

Contents

Course Rationale 5
Mark Scheme 6
Glossary of Keywords 9
Tutorial 1 – Basic Properties of Nuclei 11
Activity 1 11
Activity 2 13
Activity 3 14
Homework 1 15
Tutorial 2 - Radioactivity 17
Activity 1 18
Activity 2 19
Activity 3 19
Homework 2 20
Tutorial 3 – Nuclear Reactions 21
Activity 1 21
Activity 2 22
Activity 3 23
Homework 3 24
Tutorial 4 – Measuring Ionising Radiation 25
Activity 1 25
Activity 2 26
Activity 3 26
Homework 4 28
Tutorial 5 29
Activity 1 29
Activity 2 29
Tutorial 6 30
Reflection on feedback 31
Appendices 32
Referencing correctly 32
Using the VLE 33

Course Rationale

The course aims to disseminate the basics of nuclear physics, whilst at the same time addressing the stigma associated with words such as "nuclear" and "radiation" – words whose "bad press" is all too often unjust. Pupils will develop problem-solving and analytical skills, as well as confidence in both written and verbal communication. Tutorials will cover topics on nuclear dimensions (radius, mass, density), radioactivity (types of radiation and radioactive half-life), nuclear reactions (fission and fusion) and radiation protection (measuring radiation, investigating the effects of time, distance and shielding on the radiation level measured). For the final assignment, pupils will be given a list of topics, and choose one on which to write an essay that consolidates understanding of all key topics covered.

The course will begin by introducing the atomic nucleus, and relating back to atomic structure basics – namely electron shells, ions and isotopes. This will then be built upon with an introduction to properties of the nucleus – namely radius, volume and density. The second tutorial will outline the basics of radioactivity. There are essentially two parts to this tutorial; the first half covers the three types of ionising radiation (alpha, beta and gamma), and the second covers the concept of radioactive decay and half-life (together with some practical demonstrations). The third tutorial will focus on nuclear reactions – i.e. fission and fusion. This tutorial will build upon the equation-balancing skills learned in Tutorial 2; this time, the task is to balance reaction equations, rather than decay equations. Students will also gain knowledge of how the different types of reactors work, together with some examples of real-life reactors and associated incidents (e.g. Chernobyl). In the fourth tutorial, students will partake in some nuclear physics experiments looking at gamma ray spectroscopy of household items (e.g. smoke alarm, banana, soil samples), as well as experiments involving radioactive half-life determination and radiation protection via time, distance and shielding (attenuation of different materials).

For the final assignment, students will choose to write a report on a given isotope or set of isotopes – preferably linking in to a real-life scenario (e.g. ^{210}Po, as was used to kill Alexander Litvenenko, or ^{99}Mo and ^{99}Tc, as used in hospitals). The report should demonstrate knowledge in all topics covered in the course – for the isotope(s) involved in the case study, the properties such as nuclear radius, half-life and modes of decay should be reported, as well as which reactions produce them and how one would best protect both themselves and others from the radiation emitted.

Mark Scheme Table

	Skills	1st (70-100)	2:1 (60-69)	2:2 (50-59)
Subject knowledge	Knowledge and Understanding	o All content included is relevant to the general topic and to the specific question/title o Good understanding of all the relevant topics. o Scientific terms are defined and used accurately throughout o Clear justification on how the content included is related to the specific issues that are the focus of the assignment	o Most of the content included is relevant to the general topic and to the specific question/title o Good understanding of most the relevant topics o Scientific terms are used accurately but not always clearly defined. o Adequate justification on how the content included is related to the specific issues that are the focus of the assignment	o Some of the content included is relevant to the general topic and to the specific question/title o Good understanding on some of the relevant topics but occasional confusion on others. o Scientific terms are used mostly accurately with occasional confusion and often not defined. o Some justification on how the content included is related to the specific issues that are the focus of the assignment
Critical thinking	Research and Evidence	o Inclusion of rich sources of research findings, data, quotations or other sourced material as evidence for the claims/ ideas o Use evidence/calculations to support claims/assertions /ideas, consistently clearly and convincingly o Evidence of further reading beyond materials provided which were used in an appropriate context o Data is effectively analysed and appropriate assumptions/conclusions are reached	o Inclusion of adequate sources of research findings, data, quotations or other sourced material as evidence for the claims/ ideas o Use evidence/calculations to support claims/assertions/ideas, mostly clearly and convincingly o Evidence of further reading beyond materials provided o Data is analysed and the assumptions/conclusions that are reached are mostly appropriate	o Inclusion of some sources of research findings, data, quotations or other sourced material as evidence for the claims/ ideas o Use evidence/calculations to support claims/assertions/ideas, at times clearly and convincingly o Limited evidence of further reading beyond materials provided o There is an attempt to analyse data is and draw assumptions/conclusions
	Developing an Argument	o A point of view or position in relation to the title or question is	o A point of view or position in relation to the title or question is	o A point of view or position in relation to the title or question is

		consistently clear o Argument/proof exceptionally well-developed and well-justified o A position is clearly established in relation to the question, and is developed effectively and consistently throughout the essay o Makes links effectively between subjects that have not previously been associated o Uses concepts from the tutorials in an unfamiliar context, and does so accurately and confidently. o Content is analysed effectively to support the argument	adequately clear o Argument/proof clear and well-developed and position justified o A position is established in relation to the question, and is well-developed in most of the essay o Some evidence of linking subjects that have not previously been associated o Use some concepts from the tutorials in an unfamiliar context, but not always accurate o Analysis of content to support the argument	somewhat clear o Argument/proof clear but not well-developed o A position is established in relation to the question, and is well-developed in parts of the essay o Limited evidence of linking subjects that have not previously been associated o Limited use of concepts from the tutorials in other contexts o Some analysis of content to support the argument
	Critical Evaluation	o Moved beyond description to an assessment of the value or significance of what is described o Evaluative points are consistently explicit/systematic/reasoned/justified o Effective critiques on the reliability of sources provided	o Mostly description but some assessment of the value or significance of what is described o Evaluative points are mostly explicit/systematic/reasoned/justified o Some evidence of critiques on the reliability of sources provided	o Only description with minimal assessment of the value or significance of what is described o Evaluative points are at times explicit/systematic/reasoned/justified o Limited evidence of critiques on the reliability of sources provided
Written communication	Structure and Presentation	o Ideas are presented in paragraphs and arranged in a logical structure that is appropriate for the assignment o The introduction clearly outlines how the essay/report will deal with the issues o The conclusion summarises all the main points clearly and concisely	o Ideas are presented in paragraphs and arranged in a structure that is mostly appropriate for the assignment o The introduction adequately describes how the essay/report will deal with the issues o The conclusion summarises most of the main points clearly o Calculations,	o Ideas are presented in paragraphs and arranged in a structure o The introduction mentions how the essay/report will deal with the issues o The conclusion summarises some of the main points clearly o Calculations, formulas and methods are not always structured, clear to follow

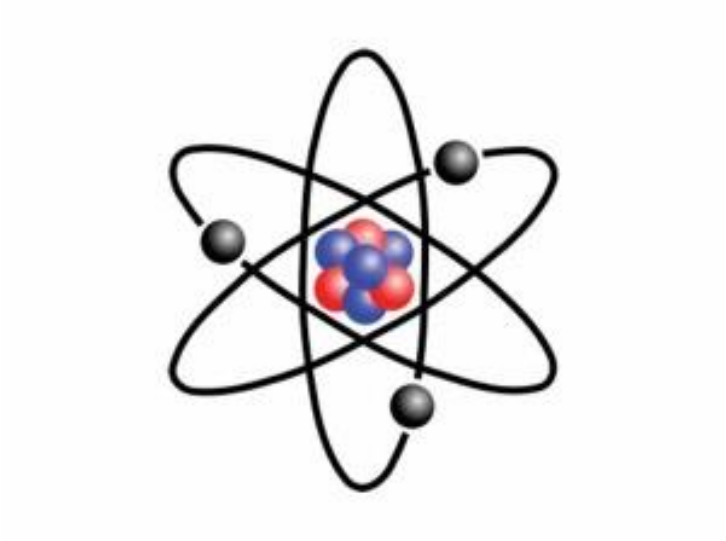
		○ All calculations, formulas and methods are clearly structured, clear to follow and correct ○ Tables and graphs are effectively constructed including appropriate headings, units and scales. ○ All sources are referenced correctly in an agreed format	formulas and methods are mostly structured, clear to follow and correct ○ Most tables and graphs are well constructed ○ Most sources are referenced correctly in an agreed format	and correct. ○ Some tables and graphs are well constructed but contains some errors ○ Some sources are referenced correctly in the agreed format with occasional errors
	Language and Style	○ No spelling, grammar or punctuation errors ○ Units and significant figures are presented accurately throughout ○ Writing style consistently clear, appropriate for scientific documents and easy to follow ○ Accurate and consistent use of technical language and vocabulary	○ Minimal spelling, grammar or punctuation errors ○ Units and significant figures are presented accurately throughout ○ Writing style mostly clear, appropriate for scientific documents and easy to follow ○ Some attempts of using technical language and vocab alary, but not always accurate	○ Some spelling, grammar or punctuation errors ○ Units and significant figures are presented accurately throughout with occasional errors ○ Writing style moderately clear, appropriate for scientific documents and easy to follow ○ Use of simple language and vocabulary effectively but struggles to use technical language

Glossary of Keywords

Word	Definition	In a sentence
atom	The smallest constituent of matter that has the properties of a chemical element	"The nucleus of a carbon-12 **atom** has 6 protons and 6 neutrons."
nucleus	The central constituent of the atom made of protons and neutrons, where virtually all of an atom's mass is concentrated	"Most of an atom's mass is concentrated within its **nucleus**."
proton	A subatomic particle with a relative mass of 1 and a relative charge of +1	"The atomic number of an element is given by the number of **protons** in the nucleus."
neutron	A subatomic particle with a relative mass of 1 and a relative charge of 0	"The mass number of an atom is given by adding together the numbers of protons and **neutrons** in the nucleus."
electron	A subatomic particle with a relative mass of 0 and a relative charge of -1	"The **electrons** in an atom orbit the nucleus in shells."
element	Species of atoms which all have the same number of protons, giving rise to their chemical properties	"Carbon is a chemical **element** with atomic number 6."
isotope	An atom same number of protons as another atom of the same element, but a different number of neutrons and therefore a different mass	"Carbon-14 is a radioactive **isotope** of carbon."
ion	An atom that has an electric charge through either gaining or losing electrons	"A doubly-charged **ion** is an atom that has lost 2 electrons."
radioactivity	The process of an unstable nucleus giving off energy in the form of radiation in order to become stable	"There are three types of **radioactivity**."
decay	The process of a radioactive nucleus either changing into a different nucleus or going to a lower energy state by means of emitting radiation	"Uranium-238 will **decay** to thorium-234."
alpha particle	A particle of two protons and two neutrons, usually emitted from very heavy nuclei	"**Alpha particles** are highly ionising but not very penetrating."
beta particle	A high-energy electron emitted from a nucleus whose proton and neutron numbers are unbalanced	"**Beta particles** are stopped by a thin sheet of aluminium."
gamma ray	A high-energy electromagnetic wave produced when a proton or a neutron goes from a higher energy level to a lower one	"When a **gamma ray** is emitted from the nucleus of an atom, there is no change to the number of protons or neutrons."

parent nucleus	The nucleus present before a reaction or decay takes place.	"The decay of the **parent** nucleus can give one or more daughter nuclei."
daughter nucleus	The nucleus resulting from a reaction or decay.	"The **daughter** nuclei produced in proton-induced fission of ^{235}U will be isotopes of lanthanum and bromine."
activity	The number of decays per second occurring in a sample of radioactive material	"The **activity** of a radioactive source is measured in becquerels."
half-life	The time taken for the number of radioactive atoms in a sample consisting of a single isotope to halve	"Some radioactive isotopes have a **half-life** of thousands of years."
fission	The process of a heavy nucleus splitting into two lighter nuclei, releasing energy in the process	"Yttrium is produced from **fission** of uranium."
fusion	The process of two nuclei fusing to form a heavier nucleus, releasing energy in the process	"Nuclear **fusion** reactions occur in the Sun."
attenuation	The reduction in intensity, or "stopping" of radiation by a material	"A gamma ray is **attenuated** more by lead than by aluminium"

Tutorial 1 – Basic Properties of Nuclei



What is the Purpose of Tutorial 1?

- To build upon prior knowledge of atomic structure
- To be able to perform simple calculations of nuclear radii and density
- To investigate variation and trends of such quantities along a chain of isotopes

Atomic structure, ions and isotopes

Atoms are made of three types of sub-atomic particle – protons, neutrons and electrons. The *nucleus*, from which the word *nuclear* derives, is made up of protons and neutrons, and accounts for almost all of an atom's mass – despite being tiny compared to the atom as a whole!

	Relative mass	Relative charge	Located
Proton	1	+1	In the nucleus
Neutron	1	0	In the nucleus
Electron	0	-1	Outside the nucleus

The electrons orbit the nucleus, rather like planets orbiting the Sun, taking up the free space that makes up most of the atom.

Activity: Draw a labelled diagram of an atom. Include the relative masses and charges of each particle on your labels.

In a "neutral" atom (i.e. one with zero electric charge), the number of protons – i.e. the *atomic number* of an element – is equal to the number of electrons. If an atom gains or loses an electron and the proton and electron numbers are no longer equal, then the atom gains a charge and becomes an ion. An atom can be ionised by knocking electrons off it, giving it a positive charge. If an atom loses one electron, it will have a relative charge of +1, and if it loses two electrons it will have a charge of +2 etc. For instance, if an electron is knocked off a copper (Cu) atom, then it becomes a Cu^{+} ion, and if it loses a second electron is becomes a Cu^{2+} ion, etc. Atoms of an element will always have the same number of protons but can have different numbers of neutrons. We call these atoms *isotopes* of the same element, and those different neutron numbers have some weird and wonderful effects on how the atom behaves! The table below shows examples of differing isotopes, one of which is *not* an isotope of the same element as the other two.

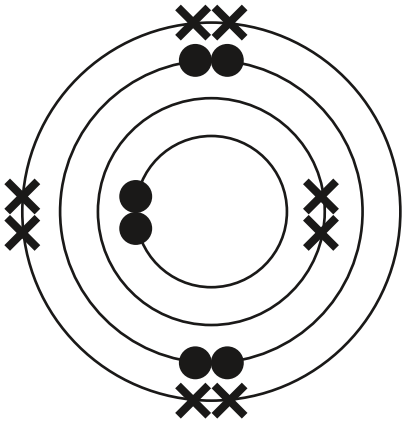
	No. of protons	No. of neutrons
^{12}C	6	6
^{14}C	6	8
^{14}N	7	7

Question: Which two of the above are isotopes of the same element?

1. _____
2. _____

Proton and neutron shells

The protons and neutrons in the nucleus exist in shells – just like the electrons orbiting it. But the rules for protons and neutrons are slightly different. We can draw a dot-and-cross diagram for protons and neutrons (dots are protons, and crosses are neutrons), remembering that the proton and neutron orbits are effectively different. So for instance, a dot-and-cross diagram for the nucleus of carbon-14 would look something like this:



Extension: For *N*=*Z* nuclei (i.e. nuclei with equal numbers of protons and neutrons), do the orbitals differ for protons and neutrons?

_____
_____
_____
_____

Activity: Draw dot-and-cross diagrams for the following nuclei: ^{9}Be, ^{11}Li, ^{22}Na, ^{42}Ca, ^{52}V

Nuclear size, shape and density

The number of neutrons present will have an effect on the size of the nucleus. The radius of an atomic nucleus can be calculated using the equation

$$R = R_0 * \sqrt[3]{A},$$

where R_0=1.2fm (=1.2*10^{-15}m). In other words, the nuclear radius is proportional to the cube root of the mass number. Of course, from the radius we can work out the volume of the nucleus. However, not all atomic nuclei are spherical, so the shape of a nucleus needs to be taken into account for this. For a spherical nucleus, the volume would simply be calculated using

$$V = \frac{4}{3}\pi * R^2 = \frac{4}{3}\pi * R_0^2 * A^{\frac{2}{3}}.$$

Activity: Work out the nuclear radius for ^{9}Be, ^{11}Li, ^{22}Na, ^{42}Ca, ^{52}V (the same nuclei as you have drawn dot-and-cross diagrams for).

The scaling of the nuclear radius with the cube root of the mass number leads to an extraordinary finding; all nuclei should, in theory, be equally dense – i.e. nuclear density is a fixed number that does not vary from isotope to isotope. If we take the standard density equation

$$\rho = \frac{m}{V},$$

and we substitute in the mass number *A* for the mass, and the formulae for both the radius and volume of a (spherical) nucleus, we get

$$\rho = \frac{A}{\frac{4}{3}\pi * R^3} = \frac{3\cancel{A}}{4\pi * R_0^3 * \cancel{A}} = \frac{3}{4\pi * (1.2 * 10^{-15})^3},$$

= 0.138kg/fm^3 – i.e. nuclear density does not depend on mass *or* radius (and therefore volume).

Homework 1

1. An ion has 49 protons, 62 neutrons and 46 electrons.
   a. What element is this?

      _____

   b. What is the isotope?

      _____

   c. What is the charge on this ion?

      _____
      _____

2. Which ion has 29 protons and 30 electrons?

   _____

3. The atomic number of yttrium (Y) is 39. How many electrons does the Y^{2+} ion have?

   _____

4. Scandium-42 (^{42}Sc) has 21 protons and 21 neutrons. Draw a dot-and-cross diagram (dots for protons, crosses for neutrons) for this nucleus.

5. Calculate the nuclear radius for ^{42}Sc.

   _____
   _____
   _____
   _____

6. Repeat the calculation for the next four Sc isotopes – i.e. $^{43,44,45,46}Sc$. Plot a graph of nuclear radius vs. mass number (i.e. *R* against *A*) for these isotopes.

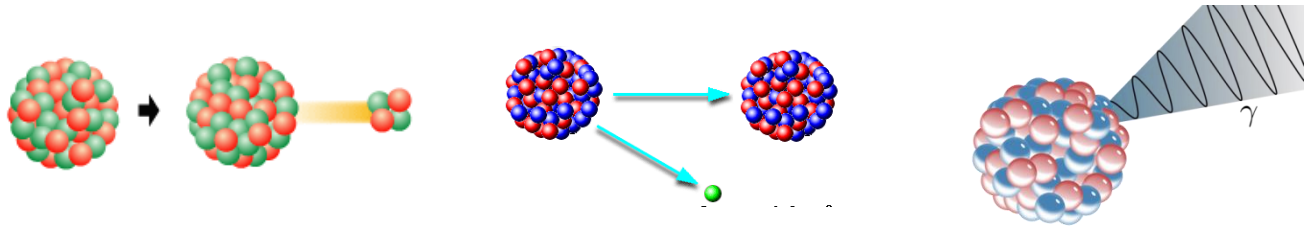
   _____
   _____
   _____
   _____

7. a. Work out the nuclear volume and density for each of these Sc isotopes, using the information given in the table below.

Isotope	Volume	Shape
^{42}Sc		
^{43}Sc		
^{44}Sc		
^{45}Sc		
^{46}Sc		

b. Calculate the density of each of these nuclei, and plot a graph of nuclear density against mass number. If you take an average value of density, how does this compare with the value given in the tutorial?

Tutorial 2 – Radioactivity



What is the Purpose of Tutorial 2?

- To be able to describe the three types of radioactive decay (i.e. alpha, beta, gamma), and which nuclei emit each
- To be able to construct and balance simple radioactive decay equations
- To be able to calculate the half-life of a radioactive isotope from graphical data

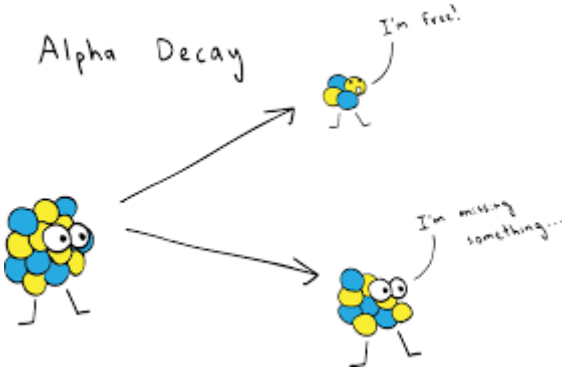
Background radiation

Radiation is all around us, all of the time. This base level of radiation in the atmosphere is called background radiation, and it is around because of cosmic rays reaching Earth from outer space. Background radiation levels are usually too low to do any lasting damage; it is when radiation levels exceed the background that they need to be dealt with.

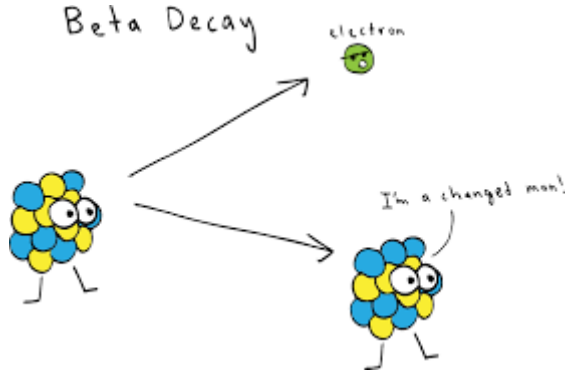
Types of radioactivity

Only a small number of isotopes are stable – there is typically only one isotope per element, although many of the heavier elements have no stable isotopes at all. Such nuclei are radioactive, and will decay to a stable nucleus by emitting radiation. The *parent* nucleus decays to produce one or more *daughter* nuclei, which often in turn undergo another decay. There are three types of radiation that an unstable nucleus can emit:

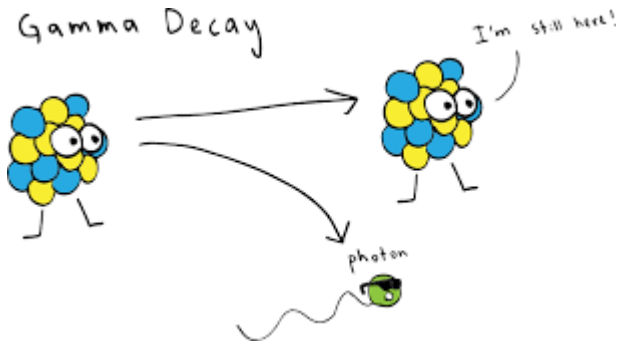
- *Alpha decay:* a bound state of two protons and two neutrons (i.e. a helium-4 nucleus). This is typically emitted by very heavy nuclei. Very heavily ionising but only stopped by skin or a thin sheet of paper.



- *Beta decay:* a high-energy electron (beta minus, β^-) or positron (beta plus, β^+), created when a neutron turns into a proton (β^-) or a proton turns into a neutron (β^+). Beta radiation is typically emitted by nuclei with unbalanced proton and neutron numbers. Beta is less ionising than alpha, but slightly more penetrating; it will be stopped by a thin sheet of aluminium. *(N.B. This electron is* ***not*** *one of the electrons orbiting the atom; it is actually created within the nucleus.)*



- *Gamma decay:* a high-energy electromagnetic wave. Gamma decay occurs when a proton or neutron makes a transition from a higher energy level (shell) to a lower one. There is no change in proton or neutron number during gamma decay. Gamma radiation is the least ionising of the three types of ionising radiation emitted by unstable nuclei, but is the most penetrating; it takes several cm's worth of lead to stop a gamma ray.



Activity: Take two hollow plastic balls and juggle them – i.e. represent an atom with two outer-shell electrons. Aim gym ball at volunteer to represent alpha, hollow plastic ball to represent beta, and switch on torch to represent gamma. This demonstrates the relative ionising power of each of the three types of radiation emitted from radioactive nuclei.

Question: In the space below, explain how this demonstration demonstrates the ionising power of each type of radiation. In your explanation, make clear what is represented by each piece of equipment used – including the volunteer themselves!

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

Radioactive decay equations

A radioactive decay can be written out in the form of an equation remarkably similar to the type of equation you write for a chemical reaction. The rules for constructing a decay equation are specific to the type of decay a nucleus undergoes. These specific rules are as follows:

- Alpha decay: the mass number decreases by 4, and the atomic number by 2
- Beta decay: mass number doesn't change, but atomic number increases by 1
- Gamma decay: no change in any numbers

Activity: Match the decay equation to the type of decay.

Equation	Type of decay
${}^{90}_{38}\mathrm{Sr} \rightarrow {}^{90}_{39}\mathrm{Y} + {}^{0}_{1}\beta$	alpha
${}^{137}_{55}\mathrm{Cs}^{*} \rightarrow {}^{137}_{55}\mathrm{Cs} + {}^{0}_{0}\gamma$	beta
${}^{238}_{92}\mathrm{U} \rightarrow {}^{234}_{90}\mathrm{Th} + {}^{4}_{2}\alpha$	gamma

Do you notice that, in all three of the equations in the above table, the sum of all atomic and mass numbers is the same on both sides of the equation? When constructing radioactive decay equations, it is important to remember that any decay equation must be *balanced* – i.e. the numbers of protons and neutrons (and therefore the sum of all mass numbers) must be the same on both sides. The total electric charge must also be the same on both sides.

Activity and half-life

Radioactive decay is a random process. You cannot predict when a particular atom will decay – but if you have enough atoms in your sample, then you can predict how many will still be radioactive after a given time interval has elapsed. The activity of a radioactive sample, measured in becquerels (Bq), is the number of atoms decaying per second in the sample. Activity is calculated via the equation

$$A = \lambda N,$$

where N is number of atoms in the sample, and λ is the *decay constant* of the isotope, measured in inverse seconds (1/s).

The time taken for the number of atoms of an isotope (and therefore the activity) to halve is called the half-life. The half-life is a property of a radioactive isotope, and different isotopes have different half-lives. For some, the half-life will be a fraction of a second, whilst for others it will be thousands or even millions of years. The half-life of a radioactive isotope can be calculated from the decay constant via the equation

$$t_{1/2} = \frac{0.693}{\lambda}.$$

Activity: You will each be given a chattering teeth toy with a drink bottle lid attached to it. This will be filled with five toy coins – each representing a radioactive atom. All coins begin being tails side up – i.e. radioactive. Wind the toys up so that they spill their coins onto the desk. Only put coins that land tails side up back in to go again; discard any coins which land heads side up. If we begin with thirty coins in total, how many do we expect to land tails side up after one go? Two goes? Three…? How many times do we wind the toys up before all coins have landed heads side up?
Plot the data in the table below and dr. What shape does the graph have?

Homework 2

1. The radioactive nucleus scandium-42 (^{42}Sc) has 21 protons and 21 neutrons. It decays to calcium-42 (^{42}Ca). The atomic number of calcium is 20. What type of decay does ^{42}Ca undergo?

   _____

2. Write the equation for this decay. Remember to balance the equation correctly.

   _____

3. Used in most conventional fission reactors, uranium-235 (^{235}U) undergoes alpha decay. What is the daughter nucleus produced? Write the equation for this decay, remembering to balance it correctly.

   _____

   _____

   _____

4. The half-life of ^{42}Sc is 681.3ms. If there are 200,000 atoms in a sample of ^{42}Sc, what is the activity of the sample?

   _____

5. Smoke alarms contain a source of americium-241 (^{241}Am), which is an alpha emitter. Write the equation for the decay of ^{241}Am.

   _____

6. The ^{241}Am source in a typical smoke alarm has an activity of 30kBq (30,000Bq). If there are $6.4*10^{14}$ ^{241}Am atoms in the source, work out the half-life of ^{241}Am in years. (1 year = $3.15*10^{7}$s)

   _____

7. The half-life of strontium-90 (^{90}Sr) is 28.8 years.

   a. Starting with one mole ($6*10^{-23}$ atoms) of ^{90}Sr, draw a decay curve (number of atoms against time) for this isotope.

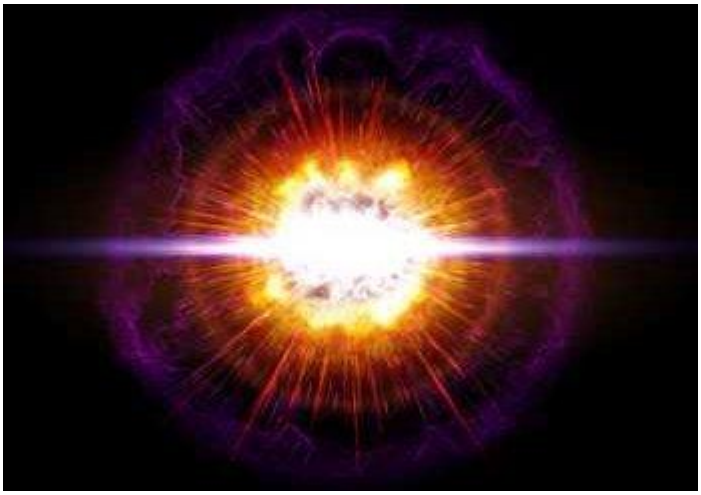
      _____

   b. How long does it take for one mole of 90Sr to completely decay?

      _____

      _____

Tutorial 3 – Nuclear Reactions

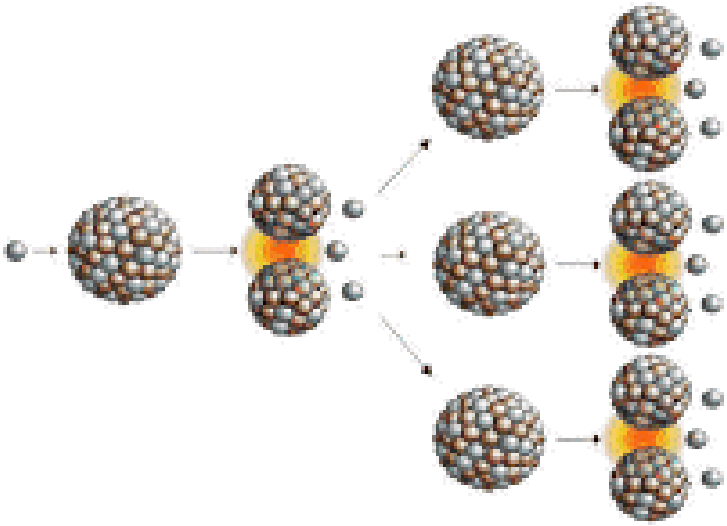


What is the Purpose of Tutorial 3?

- To be able to describe how radioactive isotopes are made
- To be able to distinguish between fission and fusion reactions
- To be able to construct and balance simple nuclear reaction equations

Nuclear fission

Nuclear fission is the process of a large nucleus (the *parent* nucleus) splitting into two lighter nuclei (*daughter* nuclei), releasing vast amounts of energy in the process. Fission can either be *spontaneous* (the nucleus just breaks apart of its own accord without any outside influence), or *induced* by firing protons or neutrons at the nucleus. *Neutron-induced fission*, in which the reaction takes place between the parent nucleus and a solitary neutron, is the process used in most nuclear power stations. This is because another neutron can be released in the fission process, which then enters the next parent nucleus, causing another fission, which releases another neutron etc. This is called a *chain reaction*, and it is how sufficient energy is generated over time in order to generate electricity.

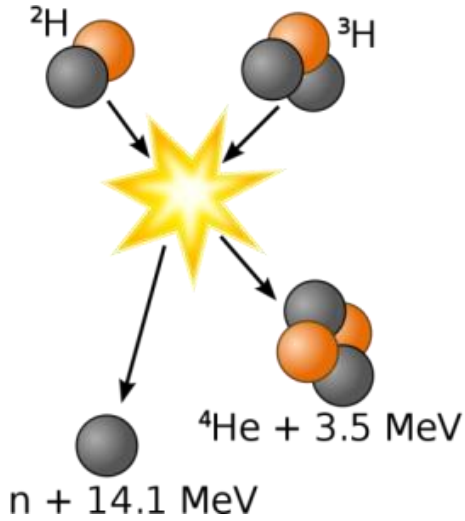


A real issue with fission reactions is that the daughter nuclei resulting from them are often radioactive, and some will have much longer half-lives than others. These serve no purpose, and often have to be buried deep underground, encased in as much lead as is needed to stop all of the alpha particles, beta particles and gamma rays from reaching us.

Activity: Take a strong rare earth magnet and surround it with non-magnetic metal ball bearings. You should find that the ball bearings are attracted to the magnet. Keep adding ball bearings to the magnet – eventually they will stop sticking to the magnet and fall off!

Nuclear fusion

Nuclear fusion is the process of fusing two nuclei together, making a larger, heavier nucleus and releasing vast amounts of energy in the process. It is the process by which energy is generated inside stars, as the temperature inside a star is high enough for the positively-charged nuclei to overcome the electrostatic repulsion between them. Much research has been done into the use of using nuclear fusion reactions to generate electricity – instead of fission reactions. However, this is extremely challenging; not only do temperatures inside the reactor need to be high enough to overcome the electrostatic repulsion between them, but the resulting plasma needs to be magnetically confined inside the reactor, as losing this gigantic magnetic field will result in the reaction mixture cooling and falling to the ground – where it'd be of no use to anyone!



Activity: Take two strong rare earth magnets and try to put like poles together. How is this demonstration a decent model for the challenges of fusion power?

_____
_____
_____

Nuclear reaction equations

The rules for constructing equations for nuclear reactions are remarkably similar to those for radioactive decay equations – i.e. they must be balanced properly! All mass number and atomic numbers must add up to give the same sum on *both sides* of the equation. Let's take proton-induced fission of uranium-235 (^{235}U) producing lanthanum-145 (^{145}La) as an example.

Large 3 means that three neutrons are produced – so as to balance both the atomic and mass numbers.
Atomic number for one neutron is zero – atomic number is proton number!

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{145}_{57}La + ^{88}_{35}Br + 3^{1}_{0}n$$

LHS: Mass number = 235 + 1 = 236
Atomic number = 92 + 0 = 92

RHS: Mass number = 145 + 88 + (3*1) = 236
Atomic number = 57 + 35 + (3*0) = 92

So, whenever you are writing out an equation for either a nuclear reaction or decay, a quick sanity check doesn't hurt – add up all the mass numbers and atomic numbers on the left and right hand sides of the equation, and see if they match!

Activity: Try writing and balancing equations for these reactions:

a) Firing a proton at a scandium-45 (^{45}Sc) nucleus, producing ^{42}Sc in the process.

b) Proton-induced fission of plutonium-239 (^{239}Pu), producing xenon-134 (^{134}Xe).

c) Fusion of two ^{3}He nuclei, producing a single ^{4}He nucleus.

In each case, remember to give whatever else is produced!

Homework 3

1. Define nuclear fission.

   _____

   _____

2. Define nuclear fusion.

   _____

   _____

3. Protons are fired at a target made of uranium-238 (^{238}U). Four different isotopes of yttrium, $^{96,97,98,99}Y$, are produced in the reaction. Write an equation for one of these reactions. Remember that an alpha particle has atomic number 2 and mass number 4, and that yttrium will not be the only product of the reaction.

   _____

4. The radioactive isotope scandium-42 (^{42}Sc) is produced via a fusion reaction, in which alpha particles are fired at a calcium-40 (^{40}Ca) target. Write the equation for this reaction. Again, ^{42}Sc will not be the only reaction product.

   _____

5. An americium-beryllium (AmBe) source is used to produce neutrons for various applications. A ^{241}Am source emits alpha particles, which strike the Be nucleus causing a neutron to be emitted.

   a. What type of reaction is taking place?

      _____

   b. Write the equation for this reaction.

      _____

   c. Research an application for an AmBe source and write a paragraph on it.

      _____

6. The JET (Joint European Tokamak) facility at Culham, Oxfordshire, uses the deuterium-tritium fusion reaction. Deuterium and tritium are both heavy isotopes of hydrogen.

   a. Write the equation for this reaction (deuterium is ^{2}H, tritium is ^{3}H)

      _____

   b. The main reaction product emits a neutron. Write the equation for this decay.

      _____

7. Write a short comparison of the advantages of fission and fusion power generation. Your answer should include the relative amounts of energy generated, the operational challenges and the health and safety concerns.

   _____
   _____
   _____
   _____
   _____
   _____
   _____
   _____
   _____
   _____
   _____
   _____
   _____
   _____

Tutorial 4 – Measuring Ionising Radiation

What is the Purpose of Tutorial 4?

- To be able to collect and analyse experimental nuclear data
- To investigate the effects of different exposure times, source-to-detector distances and shielding materials on the amount of radiation detected
- To relate experimental findings to topics learned in previous tutorials

Experiment 1: Half-life of Vanadium-52 using a sodium iodide (NaI) scintillator

- Ensure your detector is set to MCS mode (don't worry, there will be people in the lab to help you with this!)
- When you collect your sample of ^{52}V, it must be placed in front of the detector immediately (it decays fairly rapidly, so you won't get good data if you don't do this straight away!)
- Set the dwell time to 10 seconds (this is simply the time the counts are recorded in one "bin" of the histogram before moving on to the next bin)
- Choose a sufficient length of time to collect data for – even after you can tell the 52V has decayed away, you still want to include a lot of background as you'll need to subtract this later!
- Press the "Go" button to start collecting data
- When you have finished collecting data, click the "Export Data" icon. This will export the data to a CSV file that can be opened in a spreadsheet application.
- The first column in the file will be labelled "Energy (keV)". Change this to "Time (s)", and multiply each channel number by the dwell time (i.e. by 10) to obtain the time.
- Construct a scatter graph of Counts against time.
- Find the point on the spreadsheet at which background has been reached, and take an average of all background counts. Subtract this value from the counts in ALL channels to obtain the corrected counts
- Plot corrected counts against time on a separate scatter graph
- Estimate the time taken for the initial number of counts to halve, then the time taken to halve again, and then again
- Take an average of these three times; this is your value for the half-life of ^{52}V!

Experiment 2: Attenuation of gamma rays

- Make sure your detector is set to PHA mode (again, there will be people around to help you with this)
- Place a caesium-137 (^{137}Cs) source in front of the detector. ^{137}Cs emits 662keV gamma ray (see list of gamma rays appended)
- Collect a gamma ray spectrum for ten minutes. When you see the peak at 662keV, move your cursor over to the left of the peak, hold down the left mouse button and drag from one side of the peak to the other. This is now your region of interest
- The number of counts in the peak is given by the net area – you will see this, and other information, if you hover your cursor over the region of interest
- When you have finished collecting the data, make a note of the net area of the peak
- Now place a sheet of aluminium between the source and the detector, and repeat the procedure you followed for the first spectrum
- Continue to add sheets of aluminium, collecting a spectrum each time – what happened to the number of counts in the peak?
- Repeat the procedure using lead, copper and polythene – which is the best attenuator of gamma rays?

Experiment 3: Gamma ray spectroscopy of household items

- Choose a sample at random from our "box of tricks"
- Place the sample on the detector and collect a spectrum for ten minutes – how do the peaks compare with those you see using the NaI scintillator?
- Using the list of gamma rays appended, determine which isotopes are present in the household item you have chosen

List of gamma rays for various isotopes

Energy (keV)	Isotope	Origin
46.5	^{210}Pb	^{238}U
59.5	^{241}Am	Neutron capture on Uranium
63.3	^{234}Th	^{238}U
92.6	^{234}Th	^{238}U
143.8	^{235}U	^{235}U
163.3	^{235}U	^{235}U
185.7	^{235}U	^{235}U
186.2	^{226}Ra	^{238}U
205.3	^{235}U	^{235}U
238.6	^{212}Pb	^{232}Th
242.0	^{214}Pb	^{238}U
295.3	^{214}Pb	^{238}U
300.1	^{212}Pb	^{232}Th
338.3	^{228}Ac	^{232}Th
351.9	^{214}Pb	^{238}U
510.8	^{208}Tl	^{232}Th
511.0	$e^{+}+e^{-}$	Annihilation
609.3	^{214}Bi	^{238}U
661.6	^{137}Cs	Fission
727.3	^{212}Bi	^{232}Th
766.4	^{234}Pa	^{238}U
768.4	^{214}Bi	^{238}U
860.6	^{208}Tl	^{232}Th
911.2	^{228}Ac	^{232}Th
969.0	^{228}Ac	^{232}Th
1001.0	^{234}Pa	^{238}U
1120.3	^{214}Bi	^{238}U
1238.1	^{214}Bi	^{238}U
1460.8	^{40}K	Natural
1764.5	^{214}Bi	^{238}U
2204.1	^{214}Bi	^{238}U
2614.5	^{208}Tl	^{232}Th

Homework 4

Complete the analysis of the data from all three experiments, and write a short report on each. Your report for each experiment doesn't have to be too long (a couple of pages will do), but it must include the following:

- a list of the apparatus used in the experiment
- a section explaining the experimental method (i.e. the steps you took when performing the experiment)
- an analysis section, including all equations used and assumptions made
- clear working out for all calculations performed
- a conclusion and evaluation of your findings
- any external sources of information used must be referenced where appropriate

Tutorial 5 – Final Assignment

What is the Purpose of Tutorial 5?

- To carry out independent research using a wide range of resources
- To present findings of research in a clear and concise manner
- To demonstrate an ability to communicate scientific findings clearly and confidently

Final assignment

Write an essay on the isotopes involved in a case study, and deliver a short (~10 minute) presentation based on your essay. The report should be between 1,000 and 1,500 words in length, and should demonstrate an understanding of the content of all previous tutorials. Therefore, it should include:

- Calculated values of nuclear radii, volume and density
- The method of decay (i.e. whether the isotope is an alpha, beta or gamma emitter), complete with correctly-balanced decay equations
- A value for the half-life of the isotope(s) being reported – this can be looked up and referenced accordingly
- How the isotope is produced (i.e. whether it is a product of a fission or fusion reaction)
- How one would protect themselves from the effects of the radiation (time, distance, shielding)
- Illustrations and diagrams where appropriate
- Links to the real-life scenario/application (including pictures where appropriate) – *although this should not be the main focus of the report!*

Example isotopes and case studies could be:

- polonium-210 (the radioisotope used to kill Russian spy Alexander Litvenenko)
- molybdenum-99 and its decay product, technetium-99 (used in hospitals for imaging patients)
- americium-241 (used in smoke alarms)
- Uranium-235 (used in most nuclear power stations at present)

Presentation

Prepare a short presentation (~10-15 minutes) on your findings. This will be presented at the Uni Pathways conference. The presentation should summarise the key points of your essay – it doesn't have to be too detailed, but should cover the basics in such a way that the audience – who are not all going to be nuclear physicists! – will be able to follow it.

Tutorial 6 – Feedback tutorial

What is the Purpose of Tutorial 6?

- To receive feedback on final assignments.
- To share examples of best practice with the other pupils in your group.
- To write targets for improvement in school lessons.
- To reflect on the programme including what was enjoyed and what was challenging.

Final assignment feedback

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

My target for future work is…

Reflecting on Uni Pathways

What did you most enjoy about Uni Pathways?
•   •   •

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

Appendix 1 – Referencing correctly

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

What is a reference?

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

Why should I reference?

Referencing is important in your work for the following reasons:

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

When should 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:

1. A marker in your assignment: After you have used a reference in your assignment (you have read something and included it in your work as a quote, or re-written it your own words) you should mark this is in your text with a number, e.g. [1]. The next time you use a reference you should use the next number, e.g. [2].
2. Bibliography: This is just a list of the references you have used in your assignment. In the bibliography, you list your references by the numbers you have used, and include as much information as you have about the reference. The list below gives what should be included for different sources.

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

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

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

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

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

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

Appendix 2 – Using the VLE

VLE username	
VLE password	

Please remember the following key details...

- You are able log into the VLE either through the link on our website (www.thebrilliantclub.org) or going directly to the VLE site at (https://portal.thebrilliantclub.org/sign-in).
- Please update your profile with your full name and email address- this will allow you to retrieve forgotten passwords or usernames
- If you forget your log-in details you can request them to be emailed to you by clicking the link on the VLE home page. (If you are still having problems you can email: schools@thebrilliantclub.org)

What is the VLE?

The VLE is a virtual learning environment for all pupils on Uni Pathways it is used for:

- messaging your tutor
- submitting homework
- submitting your final assignment
- accessing resources for your tutorials
- finding out more information about university and careers

How should I use the VLE?

The VLE is a professional academic environment in which pupils are able to message their PhD Tutor. Here are a few things to consider:

- Ensure you keep a professional tone in the messages you send to your tutors.
- Ensure you always reply to your tutors in a timely manner.
- Thank your tutor for the effort they are putting in to give you your feedback etc.
- Submit all homework to your tutor on time.

IMPORTANT: Final assignment

- When you submit your final assignment, please remember that you need to do so through the 'My Activities' tab and not as an attachment to a message.

Notes

Notes

Notes

Journey to the Centre of the Atom

researchersinschools.org