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|  |
| Investigating isotopes |
| Information processing and data analysis |
| Student worksheet  This document and its accompanying MS Excel workbook enable students to analyse isotopic data of the first twenty chemical elements in the periodic table (hydrogen to calcium). These activities are suitable for students in Years 9 to 12.  **Students will:-**   * learn how the number of neutrons and protons in an isotope affects its nuclear properties * construct a section of the Table of isotopes, using MS Excel * investigate the properties and uses of different isotopes   **The activities provided address the following Australian Curriculum skills outcomes:**   * Analyse patterns and trends in data, including describing relationships between variables and identifying inconsistencies [(ACSIS169)](http://www.scootle.edu.au/ec/search?accContentId=ACSIS169) * Communicate scientific ideas and information for a particular purpose, including constructing evidence-based arguments and using appropriate scientific language, conventions and representations [(ACSIS208)](http://www.scootle.edu.au/ec/search?accContentId=ACSIS208)   **The activities provided address the following Australian Curriculum content statements:**   * All matter is made of atoms that are composed of protons, neutrons and electrons; natural radioactivity arises from the decay of nuclei in atoms (ACSSU177) * Isotopes are atoms of an element with the same number of protons but different numbers of neutrons; different isotopes of elements are represented using atomic symbols (for example, , (ACSCH021) * Isotopes of an element have the same electron configuration and possess similar chemical properties but have different physical properties, including variations in nuclear stability (ACSCH022) * The relative atomic mass of an element is the ratio of the weighted average mass per atom of the naturally occurring form of the element to 1/12th the mass of an atom of carbon-12; relative atomic masses reflect the isotopic composition of the element (ACSCH024) |
|  |

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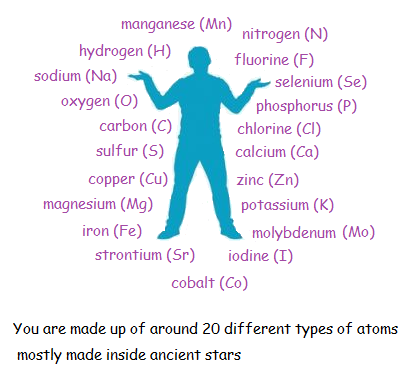
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# **We’re all about atoms**

Everything in the universe is made up of atoms –air, water, rocks and soil, stars and you! The atom is the basic building block for all matter. There are around 94 different naturally occurring atoms and everything in the universe is made up of combinations of these 94 different atoms.  It takes a lot of atoms to make up anything. Just one A4 sheet of paper is made up of approximately 300,000 billion billion atoms. Atoms last a very long time – they go on and on practically forever. Because atoms are so long lived, they really get around. Every atom in you has almost certainly been part of millions of organisms on its way to becoming you.



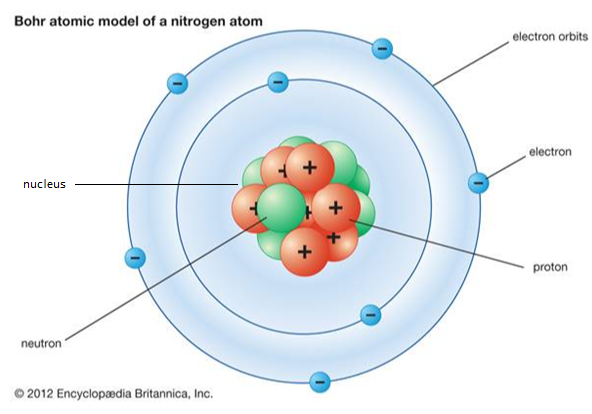
Atoms are very small. In fact 10 million atoms would fit in one millimetre on your ruler. And every atom is made up of even smaller parts called protons, neutrons and electrons. There are different types of atoms based on the number of protons each atom contains. A substance that consists of one type of atom only is called an **element**. All the known elements, both naturally occurring and man-made, are listed in a chart called the **periodic table**.

If you could see inside an atom, you would find mostly empty space. At the centre you would find an extremely small **nucleus** made up of the protons and neutrons (protons and neutrons together are called **nucleons**), while the electrons orbit in the space around this nucleus. If the atom was the size of a football field the nucleus would be only a small grape at the centre!

Atoms are electrically neutral and have the same number of electrons orbiting the nucleus as there are protons within the nucleus. This is because electrons have a negative charge (-1), whereas protons have the opposite, a positive charge (+1). Neutrons have no charge, but they are able to interact with the protons and counterbalance the electric repulsion of the protons, helping to hold the nucleus together.

Nearly all of the matter of an atom is concentrated in the protons and neutrons in the nucleus. The mass of these particles is measured in atomic mass units, abbreviated to amu. Protons and neutrons have a similar mass, with a proton’s mass being 1.0073 amu, and a neutron’s mass being 1.0087 amu. Electrons are extremely lightweight, with the mass of an electron being 0.000549 amu. In fact, protons and neutrons are actually 1830 times heavier than electrons!

But if there is no way in the world to see an atom, then how do we know that an atom is made up of protons, neutrons and electrons? Scientists in the early 1900s were able to infer a lot about the structure of an atom and to propose models of what an atom should look like from experiments that they performed to investigate its structure. The most commonly used model of the atom today is based on a model that was described by Niels Bohr in 1913.



Bohr explained that the electrons travel in discrete shells, each with its own radius. Only two electrons can fit in the lowest shell, whereas eight electrons can fit in each of the next two shells.  
Think of shells as a series of concentric spheres, each centred at the nucleus. Electrons travel around the surface of the spheres. Ordinarily, the inner shells must be filled with electrons before an electron can occupy a space in any shell that is further out. So, as you consider elements progressively up the periodic table from hydrogen, helium, lithium …., the number of electrons increases by one each time. They progressively fill the first shell, which can only hold two electrons – then the second shell, which can only hold eight electrons - then the third shell which, for the first twenty elements, also can only hold eight electrons and so on. Hence, helium has one more electron in the first shell than hydrogen: a total of two electrons for helium, which fills that first shell. Lithium has three electrons; two orbit in the innermost shell and the third one orbits in the second shell.

Each element has its own unique atom with a specific number of protons. The number of protons determines the **atomic number** of the element, which is the number for the element in the periodic table. **Isotopes** are atoms of the same element and thus have the same number of protons in the nucleus, but have a different number of neutrons, giving each isotope a different atomic mass. The **atomic mass** is determined by the total number of protons and neutrons in a nucleus. We use the atomic mass to identify the specific isotope. For example, the diagram above shows an atom of nitrogen-14. Nitrogen-15 is another isotope of nitrogen (N) which also has seven protons in its nucleus, and eight neutrons. The word **isotope** comes from the Greek, meaning “having the same place” in the Periodic Table.

ANSTO has prepared an MS Excel spreadsheet called ‘Investigating Isotopes Z1 to Z20’ for students to download to accompany this MS Word document. It lists the isotopes of the first twenty elements: from hydrogen, H, to calcium, Ca. Most elements found in nature contain a mixture of isotopes, each with a different atomic mass.

# **Further resources for students**

The following lists further resources that students may like to view as part of these activities:

1. <https://www.ansto.gov.au/education/nuclear-facts/what-is-nuclear-science>

The power of 10 video

1. <https://www.ansto.gov.au/education/apps>

ANSTO atom builder

# **questions AND Activities**

Use the background information ‘We’re all about atoms’ and accompanying MS Excel spreadsheet ‘Investigating Isotopes Z1 to Z20’ to assist you in answering the following questions.

1. Based on what you have learned from the background Information ‘We’re all about atoms’, fill in the blanks with the following words: *neutrons, nucleus, inside, protons, atoms, orbit, positive, electrons.*

All matter is made of \_\_\_\_\_\_\_\_\_\_\_\_. Atoms are composed of \_\_\_\_\_\_\_\_\_\_\_\_, neutrons and electrons.  
Protons have a \_\_\_\_\_\_\_\_\_\_\_\_ charge and are found in the \_\_\_\_\_\_\_\_\_\_\_\_ of an atom.

\_\_\_\_\_\_\_\_\_\_\_\_ have a negative charge and \_\_\_\_\_\_\_\_\_\_\_\_ the nucleus.  
 \_\_\_\_\_\_\_\_\_\_\_\_ have no charge and are found \_\_\_\_\_\_\_\_\_\_\_\_ the nucleus.

1. Construct a table to show the differences in mass, location and charge of each of the particles that make up an atom.
2. Complete the table below. You may need to review the MS Excel workbook before completing this task:-

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Isotope | Element Symbol | Number of protons | Number of neutrons | Number of nucleons |
| Hydrogen-1 | H |  |  |  |
| Lithium-5 | Li | 3 |  | 5 |
| Fluorine-18 | F |  | 9 |  |
| Fluorine-19 |  |  |  |  |
| Nitrogen-15 |  | 7 |  |  |
| Potassium-40 | K | 19 |  |  |

Define the terms ‘atomic number’ and ‘atomic mass’

|  |  |
| --- | --- |
| Term | meaning |
| atomic number |  |
| atomic mass |  |

Define the term ‘isotope’. Give an example of isotopes from the table in question c.

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The electronic structure is how the electrons are distributed in an atom. The electronic structure of an atom determines its position in the periodic table and its properties.

Complete the table below by stating the maximum number of electrons allowed in each of the electron shells of an atom for the first 18 elements.

|  |  |  |  |
| --- | --- | --- | --- |
| Shell | first shell closest to the nucleus | second shell from the nucleus | third shell from the nucleus |
| maximum number of electrons allowed in this shell |  |  |  |

1. How many electrons orbit in the outer shell of beryllium?

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1. Which element has electrons filling the first two shells, and none in the third shell?

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1. In the space below, draw Bohr atomic models for both carbon-12 and carbon-13 atoms. Compare these models (state their similarities and differences).

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1. Oxygen-18 is the starting isotope from which an important radioisotope used in medicine is made.
2. How many neutrons are present in the nucleus of oxygen-18? Explain your answer.

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1. When an oxygen-18 atom is bombarded by a proton they form two particles, an isotope and a neutron. What isotope is formed? Explain your answer.

HINT: Remember that the total number of protons and neutrons has not changed. They have just been rearranged into different particles.

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# **being radioactive**

Atoms found in nature are either stable or unstable. For an atom to be stable, it has to have the right number of neutrons for the number of protons in its nucleus. Comparing the number of neutrons to the number of protons in a nucleus is known as the neutron to proton ratio. For example, the stable isotopes of hydrogen, hydrogen-2 and hydrogen-1, have one proton and either one or no neutron in their nucleus. Whereas tritium (hydrogen-3), which is an isotope of hydrogen with a nucleus of one proton and two neutrons, has too many neutrons in its nucleus for only one proton and so is unstable. More **protons** in the nucleus need more **neutrons** to bind the nucleus together, so as the number of protons increases in an atom so the neutron to proton ratio increases for stable isotopes.

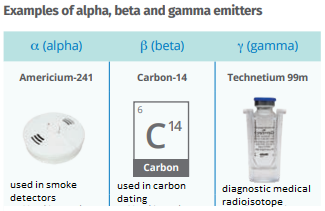
Unstable isotopes are radioactive and are called **radioisotopes**. In an attempt to become more stable, these radioisotopes will usually shed energy in the form of ionising radiation. The process of emitting ionising radiation is called **radioactive decay** and is measured using a time period called a **half-life**. One half-life is the time it takes for half the radioactive atoms of a radioisotope to disintegrate or decay into other atoms. In other words, one half-life is the time taken for a measured level of radioactivity from the radioisotope to decay to one half of that level.

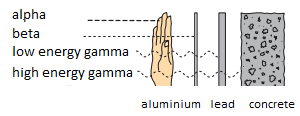
**Ionising radiation** is radiation in the form of particles and/or electromagnetic radiation, with sufficient energy to ionise or strip electrons from atoms. There are three main kinds of ionising radiation that are emitted from the nucleus:

1. **alpha** particles, which are positively charged particles made up of two protons and two neutrons

2. **beta** particles, which are essentially negatively charged electrons

3. **gamma** radiation which is a form of electromagnetic radiation and so has no charge.





Other ways in which unstable atoms can become stable include the emission of a **positron,** which is a particle that is similar to an electron but carrying a positive charge, or occasionally the nucleus will capture one of the electrons orbiting in the inner shell. This last mode is called electron capture and is quite rare. The type of ionising radiation produced by an isotope when it decays is called its **decay mode**. Column I in the accompanying Excel spreadsheet is headed ‘Main decay mode’ and shows the most common mode of decay of that isotope. Isotopes of many heavy elements decay by emitting alpha particles, but none of the isotopes of the first 20 elements decay in this way.

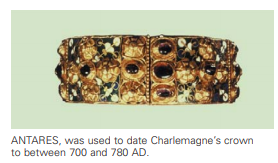
**Examples of radioisotopes used at ANSTO**

Some radioisotopes are produced from the bombardment of stable [isotopes](https://www.sciencedirect.com/topics/physics-and-astronomy/nuclides) by high energy cosmic rays. These rare radioisotopes are called **cosmogenic radionuclides**. Common cosmogenic radionuclides include beryllium-10 and aluminium-26. ANSTO is using cosmogenic radionuclide dating to work out the past extent of ice sheets in Antarctica.

Many useful radioisotopes are not sufficiently abundant in the natural environment, and so they have to be produced artificially. The OPAL nuclear reactor, which is operated by ANSTO, generates very many neutrons which are used to produce neutron-rich isotopes from stable atoms. The stable material is placed in the reactor and bombarded with the neutrons. Neutron-poor radioisotopes are produced in a cyclotron, which fires protons at particular stable atoms. Protons can be manufactured by stripping electrons from atoms of hydrogen-1.

An important neutron-poor radioactive isotope produced at ANSTO and used in many hospitals is fluorine-18. This emits positrons, which are used to diagnose medical problems. Carbon-14 is a beta emitter and is used in carbon dating. ANSTO carries out radiocarbon dating on diverse natural materials such as lake sediments, ground waters and surface waters, tree-rings, ice-cores, corals, soils and air, as well as bones. ANSTO’s particle accelerator ANTARES was used to authenticate and age the Crown of the Holy Roman Emperor, Charlemagne. The high precision analysis was performed on the bees’ wax, the adhesive used to hold the precious stones of the crown in place. The results dated the Crown to between 700 and 780 AD, close to the time Charlemagne lived. Carbon-14 has a half-life of 5,730 years and can date samples up to around 50,000 years old, as after 10 half-lives the amount of the radioisotope remaining becomes too small to be measured accurately. So when dating older objects, such as groundwater or rocks, it is necessary to use other isotopes that take a much longer time to decay. Nature has conveniently provided us with radioisotopes that have a range of half-lives allowing us to measure a very wide range of ages.

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PET scans of the brain of a smoker and non-smoker. The PET scan is performed using fluorine-18.

# **questions AND Activities**

Use the background information ‘Being radioactive’ AND the accompanying MS Excel spreadsheet ‘Investigating Isotopes Z1 to Z20’ to assist you in answering the following questions.

Using the key, draw the nuclei showing the particles present for the three isotopes of hydrogen in the table below. Name each of the isotopes.

proton neutron

|  |  |  |  |
| --- | --- | --- | --- |
| Name of isotope |  |  |  |
| Composition of nucleus |  |  |  |

The stable Isotopes of hydrogen are used to make light water and heavy water which are both used in our OPAL reactor. Compare light water with heavy water in terms of their composition and use.

(**HINT:** Hydrogen has two stable isotopes. Consider which of these stable isotopes is heavier and would be used to make heavy water.

Use the information provided in the MS Excel spreadsheet to describe their uses.)

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What causes the radioactivity of different isotopes?

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Complete the table below.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Type of radiation | symbol | consists of.. | charge | stopped by |
| alpha | α |  |  |  |
| beta | β |  |  |  |
| gamma | γ |  |  |  |

1. Column F in the accompanying Excel spreadsheet indicates whether the isotope is stable or unstable. Unstable isotopes are radioactive.
2. How many isotopes of calcium, Ca, are stable?

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1. Identify the stable isotopes of oxygen, O.

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1. Oxygen-19 is an unstable isotope of oxygen. Why do you think it is unstable?

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1. The type of ionising radiation produced by an isotope when it decays is called its **decay mode**.
2. From the accompanying Excel spreadsheet, identify isotopes from three different elements that decay by beta emission. Why do you think these isotopes are radioactive?

(**HINT**: compare each isotope to the stable isotopes of that element in terms of its number of protons and neutrons)

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1. Identify isotopes from three different elements that emit positrons as they decay. Why are these isotopes radioactive?

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1. Fluorine-18 is a medical radioisotope that is produced at ANSTO.
2. Identify the device used to create this isotope and justify your choice.

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1. The spreadsheet contains a column showing the common uses for each isotope. Describe how fluorine-18 is used.

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1. Watch the following video showing a PET scan animation <https://www.youtube.com/watch?v=oySvkmezdo0&t=1s>

Explain how fluorine-18 is useful for these scans.

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1. Read the following article.  
   <https://www.ansto.gov.au/news/multipurpose-research-reactor-providing-radiopharmaceutical>
2. What device at ANSTO is being used to create phosphorus-32?

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1. Describe the medical use of this isotope.

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1. From the accompanying MS Excel spreadsheet, identify the type of radiation being released by phosphorus-32.

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1. Radioisotopes are also used in industry. One of these is sodium-24. Use the accompanying Excel spreadsheet to:
2. state how this radioisotope is used.

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1. identify the type of radiation emitted by this isotope.

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1. The worksheet shows the half-life of all the unstable isotopes presented in various time units including milliseconds, seconds, days and years. Another column shows the half life in seconds.
2. Identify which isotope in the table has the shortest half-life.

**HINT:** You will need to sort the whole table according to half-life in seconds. The half-life in seconds is displayed using an Exponent or E, which means the number of tens you multiply a number by if the E number is positive or the number of tens you divide a number by if the E number is negative. So beryllium-7 has a half-life of 4.60E+06s or 4,600,000s, whereas lithium-11 has a half-life of 9.00E-03s or 0.009s.

Select **DATA** **tab** and click on **sort**. A dialog box will open. Choose sort by ‘half life in seconds’ with order smallest to largest, then click OK.

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1. Identify which isotope in the table has the longest half-life.

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1. ANSTO uses the radioisotopes carbon-14, chlorine-36 and tritium (hydrogen-3) to determine the age of groundwater, such as those in Australia’s Great Artesian Basin which are up to one million years old. The isotope used to date the groundwater depends on the age of the groundwater and the half-life of the isotope.

State the half-life of each of the three isotopes. Which of the isotopes would be used to date the water of the Great Artesian Basin? Give a reason for your choice.

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1. Bananas contain the element potassium and are slightly radioactive. Explain why they are radioactive.

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1. What is a ‘cosmogenic radionuclide’? Give two examples, and state the half-life of each and their decay mode.

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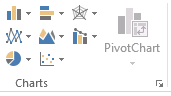
# **Data Analysis (numeracy and ICT)**

Use the data provided in the accompanying MS Excel spreadsheet ’Investigating Isotopes Z1 to Z20’ to complete the activities and to assist you in answering the following questions.

1. Using Excel tools, construct a scatter graph of the **number of** **neutrons versus the number of protons** for all the isotopes of elements 1 to 20 shown in the MS Excel spreadsheet. Your graph should also indicate which isotopes are stable and the decay mode of each of the unstable isotopes.

**HINT:** To construct your graph you can follow the instructions below.

1. Select **Data** tab and click on **Sort**. A dialog box will open. Choose sort by column F (stable / unstable), then by Column I (main decay mode), both with order A-Z, then click OK.
2. For the stable isotopes, highlight the data in Column B (protons) and Column C (neutrons).
3. Select **Insert** tab and choose **scatter graph** from the charts shown, and click on the first scatter graph in the dialog box.



1. Right click in the plot area of the chart and choose **select data**.
2. In the dialog box, select **edit** and in the second dialog box that opens type in the series name ‘**Stable**’. Click OK.
3. Select **add** in the dialog box.
4. In the second dialog box that opens type in the series name ‘**Beta**’(decay mode).
5. Click in the series X values then highlight the column B protons data for the isotopes that have ‘beta’ in the decay mode column I.
6. Click in the series Y values, delete ={1} and highlight the column C neutrons data for the isotopes that have ‘beta’ in the decay mode column I. Click OK.
7. Repeat steps 6, 7, 8, 9 to add a new series name ‘**Electron capture**’ (decay mode) to the graph, highlighting the appropriate data for ‘electron capture’ from column B for step 8 and column C for step 9.
8. Repeat steps 6, 7, 8, 9 to add a new series name ‘**Positron**’ (decay mode) to the graph, highlighting the appropriate data for ‘positron’ from column B for step 8 and column C for step 9.
9. Select **design** tab under **chart tools**, and click on **add chart element** to add a legend, axes titles (primary horizontal – proton number and primary vertical – neutron number) and chart title (Isotopes of the first 20 elements with a half-life greater than 1 millisecond).
10. What makes an isotope stable?

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1. A ratio is a comparison of two numbers or measurements. Ratios tell us how much of one we have in relation to another.

What is the ratio of unstable isotopes to stable isotopes for the isotopes of the first 20 elements given in the MS Excel spreadsheet?

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1. The data points on your graph should appear in distinct columns.
2. Explain what is common between all the data points in any one column.

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1. From the first 20 elements, identify the element(s) with the most isotopes with half-life greater than 1 millisecond.

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1. From the first 20 elements, identify the element with the most stable isotopes.

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1. Describe any observed patterns or trends shown by the graph.

(**HINT**: consider the different decay modes of the radioisotopes and their location on the graph in relation to the stable isotopes.)

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1. Account for (give reasons for) any observed patterns or trends you described in question e. above, in terms of the composition of the nucleus of the radioisotopes.

(**HINT**: consider why each of these groups of isotopes are unstable in terms of the number of neutrons for the number protons in their nucleus)

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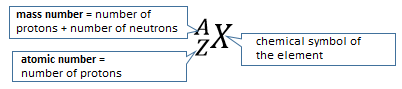
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1. Complete the following passage with the correct decay modes:  
   Radioisotopes with too many neutrons generally decay by ……………………………………………………  
   Radioisotopes with too few neutrons generally decay by ………………………………………………………

# EXTENSION ACTIVITY: Atomic structure and atomic mass

Every isotope has a chemical element symbol, and a defining atomic number, given the symbol Z. The atomic number or **Z** was named from the German word for number, Zahl, and it shows the number of protons in the nucleus of that isotope. Isotopes also have an atomic mass or mass number, represented by the symbol A, which gives the nucleon number, that is, the total number of protons and neutrons in the nucleus.

The composition of any isotope can be described using the following representation:



During radioactive decay, an unstable nucleus emits radiation and is often transformed into the nucleus of another element. We can write a nuclear equation to describe this nuclear reaction, and show the rearrangement of subatomic particles that occurs, using the representation above to identify the isotopes and other particles involved in the reaction. Using this representation a beta particle is indicated by and a positron, being a particle with the same mass as an electron but having a positive charge, is shown by .

The beta particle is produced when a neutron in the nucleus decays. When a neutron disintegrates, it turns into a proton and an electron. The proton remains in the nucleus, and the electron is emitted as a beta particle. In contrast, a positron comes from the breakdown of a proton in the nucleus. When a proton disintegrates, it turns into a neutron and a positron. The neutron remains in the nucleus and the positron is emitted. In both cases the number of protons in the nucleus changes, so the atom has now become a different element.

Nuclear reactions are always **balanced**. When a nuclear reaction occurs, the sum of the mass numbers of the reactants equals the sum of the mass numbers of the products. Also the sum of the atomic numbers of the reactants equals the sum of the atomic numbers of the products. The equation below represents the decay of oxygen-15 to form the stable isotope nitrogen-15. Oxygen-15 is used in Positron Emission Tomography (PET) scans to label oxygen, carbon dioxide and water in order to measure blood flow, blood volume, and oxygen consumption.

7 + +1

*atomic* number: 8 =

mass number: 15 =

15 + 0

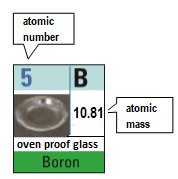
🡪 +

Have you ever wondered why the **atomic mass** of an element as stated on a periodic table is often not a whole number? This is because the atomic mass (also referred to as the atomic weight) of an element is a weighted average of all of the naturally occurring isotopes of that element. It is determined by two factors:

* The atomic mass of each naturally occurring isotope of the element
* The natural relative abundance of each isotope

The **atomic mass**of an isotope is measured in *atomic mass units*(amu). One amu is defined as the mass of of a carbon-12 atom. The atomic mass of an element is the **sum** of the atomic mass of each isotope, in amu, multiplied by the abundance of that particular isotope.

For example, boron has two stable isotopes: boron-10 which has an atomic mass of 10.013 amu and makes up 19.9% of naturally occurring boron, and boron-11 which has atomic mass of 11.009 amu and is 80.1% of boron in the natural environment. All of its other isotopes are unstable with very short half-lives, and very low natural abundance, and so are not included in the determination of the atomic mass of naturally-occurring boron.



Hence, the atomic mass of boron is equal to

(0.199 x 10.013) + (0.801 x 11.009) = 10.811 amu

# **questions AND Activities**

Use the background information ‘Atomic structure and atomic mass’ to assist you in answering the following questions.

1. Define the term ‘nucleon’.

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1. The accompanying MS Excel spreadsheet ‘Investigating isotopes Z1 to Z20’ shows the atomic number for each of the listed isotopes. An isotope of one element may have the same atomic mass (A value) as an isotope of a different element.

Identify three examples of such pairs from the MS Excel spreadsheet provided.

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1. Scientists have agreed on the following representation to describe an isotope:

Use this information to complete the table below.

|  |  |  |  |
| --- | --- | --- | --- |
| Isotope | Isotope representation | Number of protons (Z) | Number of neutrons |
| hydrogen-2 (deuterium) |  |  |  |
| hydrogen-3  (tritium) |  |  |  |
| helium-3 |  |  | 1 |
| carbon-14 |  | 6 |  |
|  |  |  |  |

1. State the representation used for each of the following

|  |  |
| --- | --- |
| type of ionising radiation | symbol representation |
| positron |  |
| beta particle |  |
| alpha particle (helium-4) |  |

1. When a beta particle is emitted from an unstable isotope, an atom of a different element is formed.

Explain this **transmutation** in terms of changes occurring in the nucleus of the unstable isotope.

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1. Explain why the emission of a positron from an unstable isotope produces an atom of a different element.

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1. Complete each of the following nuclear equations by adding the missing part in the box:

🡪 +

🡪 +

🡪 +

🡪 +

1. Fluorine-18 is the most widely-used positron emitting radioisotope. It is used in a variety of research and diagnostic applications, including to detect brain tumours.

Write a nuclear equation to show the decay of fluorine-18 and identify the isotope that is formed.

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1. Due to its high potassium content, eating a banana will provide you with a dose of 0.1 μSv of radiation from the naturally-occurring potassium-40 isotope.

1. Use the accompanying Excel spreadsheet to state the decay mode of potassium-40.

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1. Write a nuclear equation to represent the decay of potassium-40 and identify the isotope that is formed.

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1. Silicon irradiation, known as neutron transmutation doping (NTD), is conducted in the OPAL reactor at ANSTO in order to transform pure silicon from a non-conductor into a semi-conducting material. When the silicon is bombarded by neutrons in the reactor, a radioactive isotope of silicon, silicon-31, is formed.
2. Using the accompanying Excel spreadsheet, state the type of radiation emitted from silicon-31.

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1. Write a nuclear equation to show the decay of silicon-31 and identify the isotope that is formed to take the place of the silicon-31 atom.

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1. The ANSTO Periodic Table of the Elements poster (see link below) shows the atomic weight of every element, which takes into account the abundance and atomic masses of each of its naturally occurring isotopes.

<https://www.ansto.gov.au/sites/default/files/2019-01/ANSTO_Periodic_Table_Poster_Web.pdf>

Several web sites are accessible that show the relative abundance and atomic mass for each of the naturally occurring isotopes of many elements. One site is:-  
<https://physics.nist.gov/cgi-bin/Compositions/stand_alone.pl>

1. Using this website state the percentage abundance and atomic mass for all the naturally occurring isotopes of the element chlorine, Cl.

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1. Calculate the atomic mass for the element chlorine and compare your answer to that shown on the ANSTO Periodic table.

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1. (i) Using the website above, state the relative percentage abundance and atomic mass for

all the naturally occurring isotopes of the element magnesium, Mg.

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1. Calculate the atomic mass for the element magnesium and compare your answer to that shown on the ANSTO Periodic table.

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