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NCEA PHYSICS LEVEL 2

AS 91172 – 2.5
Demonstrate understanding of atomic and nuclear physics

Revision Workbook

+

Interactive Web-based Learning

Trevor Castle

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Achievement Standard Physics 2.5
Demonstrate understanding of atomic and nuclear physics

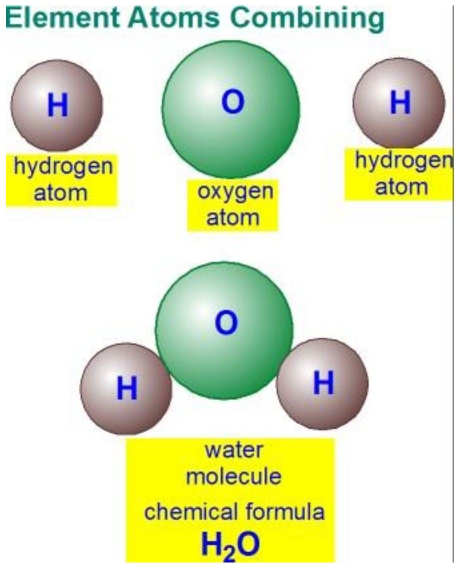
This module discusses: *Models of the atom (Thomson and Rutherford),gold foil experiment.*

Learning Outcomes: *By the end of this module you will be able to:*

1. *Describe the atomic models of Dalton, Thomson and Rutherford.*
2. *Define an element, an atom, a proton, a neutron and an electron.*
3. *Describe Rutherford's alpha particle scattering experiment.*
4. *State that the atomic number Z is the number of protons in a nucleus.*
5. *State that the mass number A is the number of nucleons in a nucleus*
6. *Determine the number of neutrons N in a nucleus.*
7. *Analyse the structure of an atom of an element.*

1. Modelling the Atom

Lesson Point 1: Dalton's Model of the Atom



The diagram shows two atoms of the element hydrogen, chemically combining with an atom of the element oxygen, to produce a molecule of the chemical compound water.

1. In 1808, **John Dalton, the English Chemist**, *proposed that an element is made up of atoms and that every element has its own kind of atom.*
2. **An element** *is a basic chemical which cannot be broken down into a simpler substance.*
3. There are 92 naturally occurring elements and a number which are artificially made.
4. ***An atom** is the smallest particle of an element which can have the element's properties.* All hydrogen atoms are the same, as are oxygen atoms.
5. If an atom is split up, its parts would no longer have the chemical properties of the element.
6. Atoms chemically bond together to produce a molecule of a compound.
7. The chemical formula for water is **H_2O**, showing the water molecule contains two atoms of hydrogen and one atom of oxygen, chemically combined.

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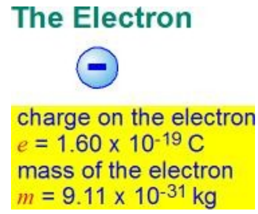
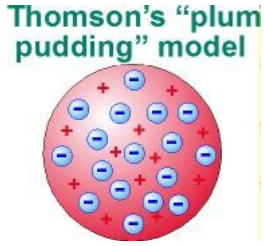
Lesson Point 2: Thomson's and Rutherford's Models of the Atom

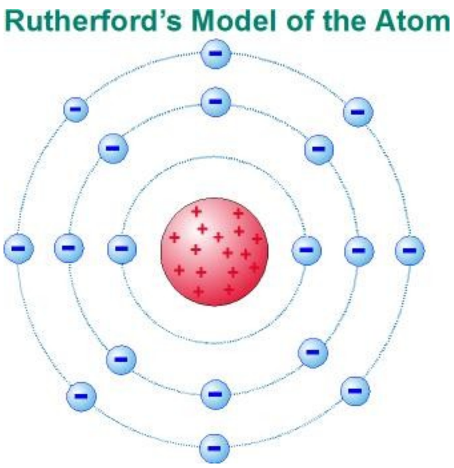


The diagram shows the electron.

1. J. J. Thomson, an English physicist, discovered the electron, which is an extremely small particle, present in all matter. It is much smaller than the lightest atom.
2. The electron has a *negative* charge.
3. The diagram shows Thomson's model of the atom, proposed in 1903.

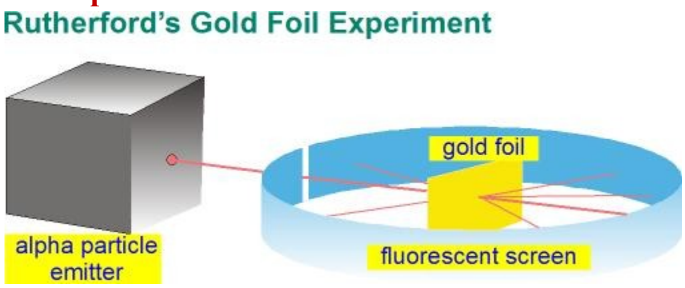


4. J. J. Thomson suggested that all matter should be thought of as a combination of negatively charged electrons and some positively charged matter. Virtually all the mass of an atom is positively charged
5. His model of the atom is mainly positively-charged matter with negative electrons stuck in it, like plums in a pudding.
6. Thomson's model is a solid matter atom.
7. The diagram shows Rutherford's model of the atom, proposed in 1911.



8. Ernest Rutherford, a New Zealander, suggested an alternative model.
9. His orbital model of the atom, has a small, central, positively charged nucleus, surrounded by electrons in circular orbits.
10. Rutherford's model is mainly space. The nucleus has virtually all the mass of the atom, but is very small compared to the size of the atom.

Lesson Point 3: Rutherford's Gold Foil Experiment



The diagram shows Rutherford's gold foil experiment.

1. Rutherford asked the question; are the atoms in a piece of gold foil solid matter, as predicted by J. J. Thomson's model, or are they mainly space, as in his own model?
2. Rutherford's proposed experiment was to take a radium source emitting a beam of alpha particles, which are positively charged. The beam was sent through the gold foil, surrounded by a fluorescent screen. Any alpha particles coming away from the foil, will strike the screen, producing tiny flashes of light. The experiment is carried out in a totally dark room.

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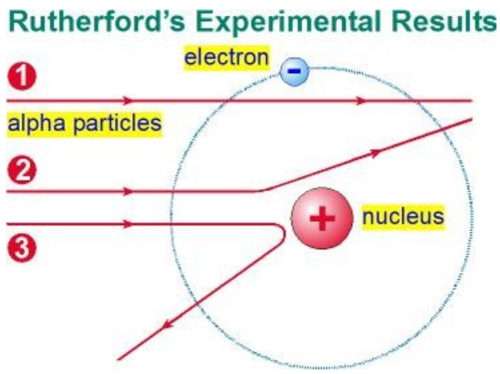
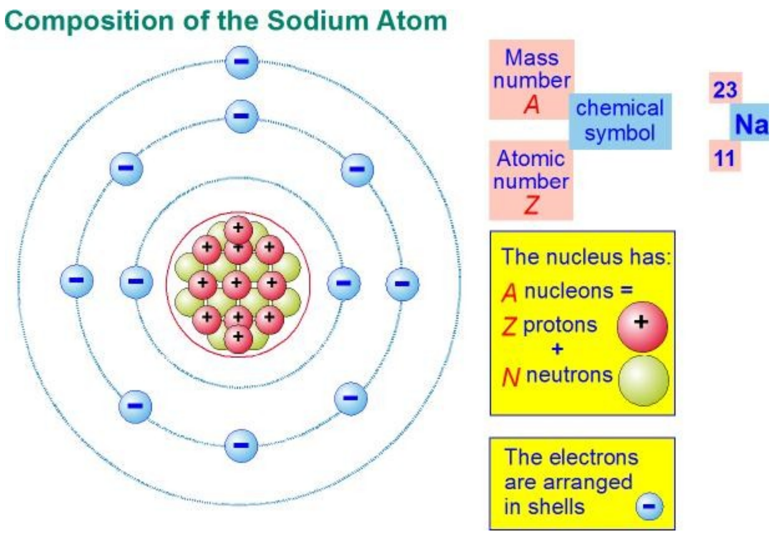
3. The diagram shows the results of the experiment.
4. Most alpha particles passed straight through the foil (path 1).
5. This was a confirmation that the gold atoms were mainly space.
6. Some alpha particles were scattered appreciably (path 2) and a very few were deflected through more than 90^o.



7. Rutherford explained that if a positively charged alpha particle came in the vicinity of a positively charged gold nucleus, the electric repulsive force between them would deflect the alpha particle.
8. The very unlikely event of a head-on collision of an alpha particle with a very small gold nucleus would cause a large deflection of the alpha particle.
9. The experiment supported Rutherford's model over that of Thomson's.

Lesson Point 4: Composition of the Atom

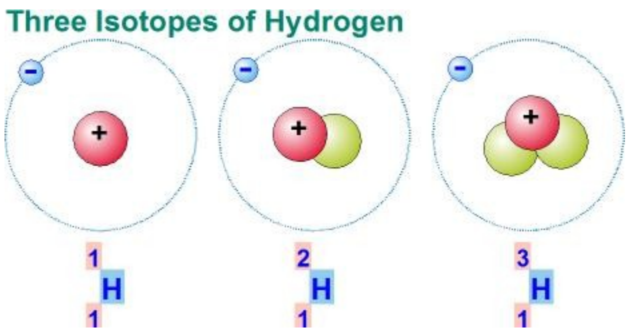
The diagram shows the composition of the atom of the element sodium.



1. At the centre of the atom is the **nucleus** which is tiny compared to the size of the atom and contains virtually all the mass of the atom.
2. The nucleus is made up of two different types of particles:
3. **The proton** which has a positive charge equal but opposite to the electron, but a much larger mass.
4. **The neutron** which is neutral (has no charge) and a mass about the same as the proton.
5. The atom of an element is represented by its chemical symbol and its atomic and mass numbers.
6. The chemical symbol for sodium is **Na**.
7. The **mass or nucleon number** A is the number of nucleons in the nucleus of the atom.
8. A **nucleon** is any particle in the nucleus.
9. The mass or nucleon number A for sodium is 23, as there are 23 nucleons in the nucleus of the sodium atom.
10. The **atomic or proton number** Z is the number of protons in the nucleus of the atom.
11. The atomic or proton number Z for sodium is 11, so there are 11 protons in the nucleus of the sodium atom.

12. The **neutron number** N is the number of neutrons in the nucleus of the atom.
13. The neutron number N for sodium = mass number – atomic number = 23 – 11 = 12 neutrons in the nucleus of the sodium atom.
14. An **electrically neutral atom** *has the same number of negatively charged electrons as positively charged protons.* The sodium atom has 11 electrons.
15. The electrons are arranged in **orbital shells** (or energy levels). *The innermost shell can take up to two electrons and the next two shells can take up to eight electrons each*. The sodium atom has 2 electrons in the first shell, 8 electrons in the second shell, and the remaining electron in the third shell.
16. The centripetal force holding electrons in circular orbits around the nucleus is the **electric force** *attracting the negatively charged electrons to the positive charge of the protons in the nucleus.*
17. A strong **nuclear force** *binds the protons and neutrons together in the nucleus and prevents the protons from pushing each other apart, by the electric repulsive forces between positive charges.*

Lesson Point 5: Isotopes of Elements



The diagram shows three isotopes of the element hydrogen.

1. Isotopes *are atoms of the same element having a different number of neutrons.*
2. The chemical symbol for hydrogen is H.
3. The atomic number *Z* for hydrogen is 1, indicating there is one proton in the nucleus of each of the three isotopes.
4. The mass number for the three isotopes has values of 1, 2 and 3 respectively.
5. The number of neutrons in each of the three isotopes is given by:
6. The number of neutrons in the first isotope = mass number – atomic number = 1 – 1 = 0.
7. The number of neutrons in the second isotope = mass number – atomic number = 2 – 1 = 1.
8. The number of neutrons in the third isotope = mass number – atomic number = 3 – 1 = 2.
9. When the atom of each isotope is electrically neutral, there will be one electron orbiting each nucleus.

COMPUTER WORK

Log on to Live-wire Learning and answer the questions.

MODULE	First Attempt /10	Working at	Second Attempt /10	Working at
Modelling the atom – Achieved Only				
Modelling the atom				

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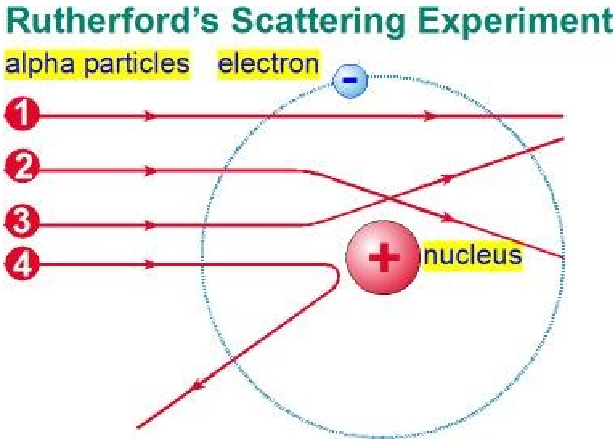
Merit and Excellence Level Questions

Q.1. The diagram shows four paths which may have been taken by alpha particles in Rutherford's scattering experiment.



a) Why is path 1 possible?

b) Why is path 2 not possible?

c) Why is path 3 possible?

d) Why is path 4 possible?

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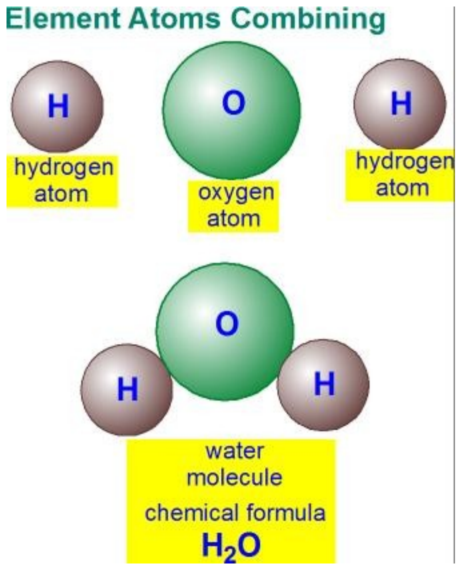
Q.2. The diagram shows two atoms of the element hydrogen, chemically combining with an atom of the element oxygen, to produce a molecule of the chemical compound water.



Write into the paragraph below the appropriate words from the list below.

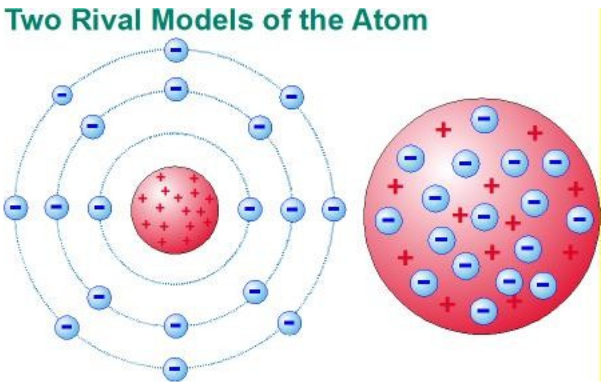
List

atom molecule element formula compound hydrogen element oxygen

John Dalton stated that an element is made of atoms and that every _______________ has its own kind of _______________ . An _______________ is a basic chemical which cannot be broken down into a simpler substance. An _______________ is the smallest particle of an element which can have the element's properties. Atoms bond together, to produce a _______________ of a _______________ . The chemical _______________ for water is H_2O, showing the water _______________ contains two atoms of _______________ and one atom of _______________ , chemically combined.

Q.3. The diagram shows two rival models of the atom.

a) Write into the paragraph below the appropriate words from the list below.



List

space solid mass matter positively negatively protons electrons nucleus circular

Thomson's model is a _____________ matter atom. Thomson suggested that all _____________ should be thought of as a combination of negatively charged _____________ and some _____________ charged matter. _____________ charged _____________ are embedded in _____________ charged matter.

b) Write into the paragraph below the appropriate words from the list below.

List: space solid mass positively negatively protons electrons nucleus circular

Rutherford's model is mainly _____________. His model of an atom, had a small, central, _____________charged _____________, containing nearly all the _____________of the atom, surrounded by _____________in _____________orbits.

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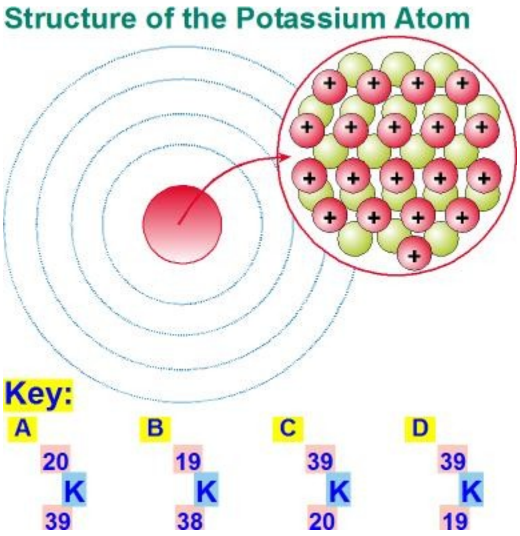
Q.4. The diagram shows part of the structure of the potassium atom. The nucleus has been enlarged. The diagram also shows a key of four possible representations for the atom, labelled **A** to **D**.



a) What is the atomic number of potassium?

b) What is the number of neutrons in the potassium atom?

c) What is the mass number of potassium?

d) What is the number of electrons in the orbital shells of an electrically neutral potassium atom?

e) What is the number of electrons in the first orbital shell of an electrically neutral potassium atom?

f) What is the number of electrons in the second orbital shell of an electrically neutral potassium atom?

g) What is the number of electrons in the third orbital shell of an electrically neutral potassium atom?

h) What is the number of electrons in the fourth orbital shell of an electrically neutral potassium atom?

i) What is the letter of the correct representation of the potassium atom, from the key shown in the diagram?

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This module discusses: *Nuclear transformations: radioactive decay (half life), fission and fusion reactions. Conservation of atomic and mass number. Products of nuclear transformation: power generation, $E = mc^2$, $P = E/t$, properties of nuclear emission (ionising ability, penetration ability).*

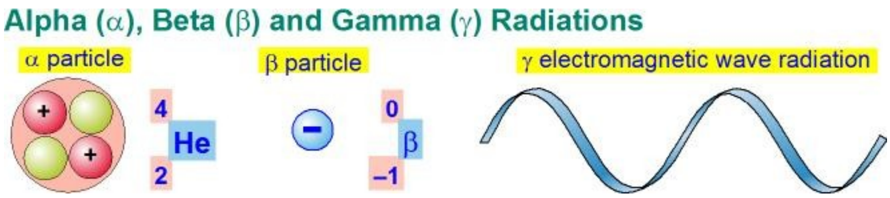
Learning Outcomes: *By the end of this module you will be able to:*

1. *Define radioactive decay.*
2. *Define half life for a decaying radioactive sample.*
3. *State the composition and properties of alpha (α), beta (β) and gamma (γ) radiations.*
4. *State and use the conservation of atomic and mass number in alpha (α), beta (β) and gamma (γ) emission reactions.*
5. *Describe the ionising ability, penetration ability and behaviour in a magnetic field of alpha (α), beta (β) and gamma (γ) radiations.*
6. *Describe Einstein's mass-energy equivalence.*
7. *Recognise and use Einstein's mass energy equivalence formula $E = mc^2$.*
8. *Describe nuclear power generation.*
9. *Recognise and use the power formula $P = E/t$.*

2. Radioactive Decay

Lesson Point 1: Alpha (α), Beta (β) and Gamma (γ) Radiations

The diagram shows alpha (α), beta (β) and gamma (γ) radiations.



1) The **nuclei of radioactive materials** *will spontaneously break up and emit particle or wave radiations*.
2) Ernest Rutherford, in 1899, discovered three naturally occurring radioactive emissions emitted by radioactive materials, which he called alpha (α), beta (β) and gamma (γ) radiations.
3) An ***α* particle** *is a helium nucleus*. It has the chemical symbol **He**.
4) The **atomic or proton number** *Z is the number of protons in the nucleus of the atom.*
5) The atomic or proton number *Z* for helium is 2, so there are 2 protons in a helium nucleus.
6) **The proton** *has a positive charge equal but opposite to the electron, but a much larger mass.*
7) The helium nucleus has a positive charge twice the negative charge of the electron.
8) **The neutron** *is neutral (has no charge) and a mass about the same as the proton.*

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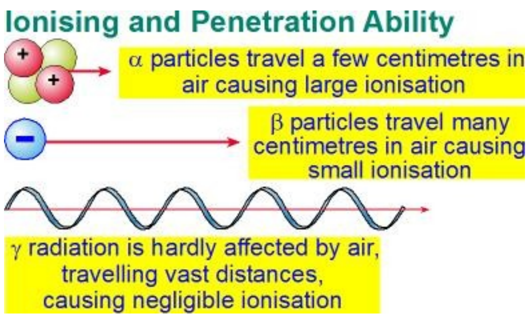
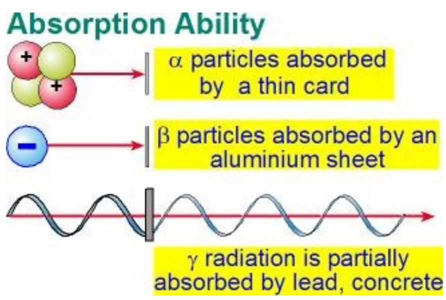
9) The **neutron number** *N is the number of neutrons in the nucleus of the atom.*
10) The neutron number *N* for helium = 2, so there are 2 neutrons in a helium nucleus.
11) The **mass or nucleon number** *A is the number of nucleons in the nucleus of the atom.*
12) A **nucleon** *is any particle in the nucleus.*
13) The mass or nucleon number *A* for helium is 4, as there are 4 nucleons in a helium nucleus.
14) A **β particle** *is an electron which comes from the nucleus.* It is not one of the electrons orbiting the nucleus.
15) The mass or nucleon number *A* for a β particle is 0, as the mass of an electron is much smaller than a proton or neutron.
16) The atomic or proton number *Z* for a β particle is -1, because an electron has a negative charge, equal and opposite to that of a proton.
17) **γ radiation** *is an intense electromagnetic wave (electric and magnetic ripples) coming from a radioactive nucleus.* Their wavelength range is about 0.1 nm (0.1 x 10^{-9} m).

Lesson Point 2: Ionising and Penetration Properties of α, β and γ Radiations



The diagram shows alpha (α), beta (β) and gamma (γ) radiations travelling through air.

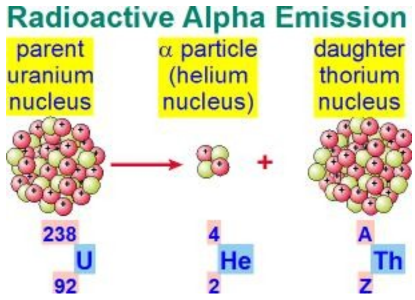
1) The **penetration ability of a radiation** *is how far it travels before being absorbed.*
2) An α particle travels only a few centimetres.
3) A β particle travels many centimetres.
4) γ radiation travels right through, virtually unaffected.
5) The **ionisation ability of a radiation** *is how much ionisation (production of charged particles) is produced by the radiation.*
6) In general, the quicker the radiation is absorbed, the more ionisation is caused.
7) Ionising emissions are dangerous. When they pass through biological matter, they leave a trial of ions in their wake, disrupting molecules and upsetting the delicate chemistry of life.



The diagram shows how alpha (α), beta (β) and gamma (γ) radiations may be absorbed.

8) The **absorption ability** *is a measure of how much material is needed to protect against the harmful nature of the radiation.*
9) α particles may be absorbed by a thin card.
10) β particles may be absorbed by an aluminium sheet.
11) γ radiation is only partially absorbed by large thicknesses of lead or concrete.

Lesson Point 3: Nuclear Reactions Producing α, β and γ Radiations



The diagram shows a natural nuclear reaction which produces α particles.

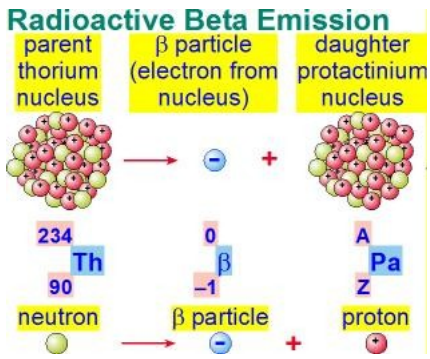
1) The unstable parent nucleus of a particular isotope of uranium, chemical symbol **U**, produces a daughter nucleus of thorium, chemical symbol **Th**, by emitting an α particle.
2) Two principles can be applied to a nuclear reaction:

   First Principle: Conservation of charge: *total charge remains constant.*

   a. The uranium nucleus has an atomic number of 92 so there are 92 protons in the parent nucleus of uranium.
   b. The α particle has an atomic number of 2 so there are 2 protons in the α particle.
   c. *The total charge is conserved in the reaction*. There are 92 protons before the reaction so there must be 92 protons after the reaction. The daughter nucleus of thorium must have the remaining 90 protons, so its atomic number *Z* must be 90.

   Second Principle: Conservation of mass number: *total number of nucleons (neutrons plus protons) remains constant.*

   a. The uranium nucleus has a mass number of 238 so there are 238 nucleons in the parent nucleus of uranium.
   b. The α particle has a mass number of 4 so there are 4 nucleons in the α particle.
   c. *The total number of nucleons is conserved in the reaction*. There are 238 nucleons before the reaction so there must be 238 nucleons after the reaction. The daughter nucleus of thorium must have the remaining 234 nucleons, so its mass number *A* must be 234.
   d. The uranium nucleus contains 238 nucleons, of which 92 are protons. It must contain 238 – 92 = 146 neutrons.
   e. The α particle contains 4 nucleons, of which 2 are protons. It must contain 4 - 2 = 2 neutrons.
   f. The thorium nucleus contains 234 nucleons, of which 90 are protons. It must contain 234 – 90 = 144 neutrons.



The diagram shows a natural nuclear reaction which produces β particles.

1) The unstable parent nucleus of a particular isotope of thorium, chemical symbol **Th**, produces a daughter nucleus of protactinium, chemical symbol **Pa**, by emitting a β particle.
2) Applying the two conservation principles to this nuclear reaction:

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1. Conservation of charge: *total charge remains constant.*

a. The thorium nucleus has an atomic number of 90 so there are 90 protons in the parent nucleus of thorium.

b. The β particle is an electron that has come from the nucleus of thorium, which only contains protons and neutrons!

c. In fact a neutron in the thorium nucleus has split into a proton and an electron (the β particle).

d. Because of this creation of an extra proton, the atomic or proton number for a β particle is -1, to balance the +1 for the extra proton.

e. *The total charge is conserved in the reaction*. There is a +90 charge before the reaction, so there must be a +90 charge after the reaction. The atomic number *Z* for the daughter protactinium nucleus must be 91, so this nucleus must contain 91 protons.

2. Conservation of mass number: *total number of nucleons (neutrons plus protons) remains constant.*

a. The thorium nucleus has a mass number of 234 so there are 234 nucleons in the parent nucleus of thorium.

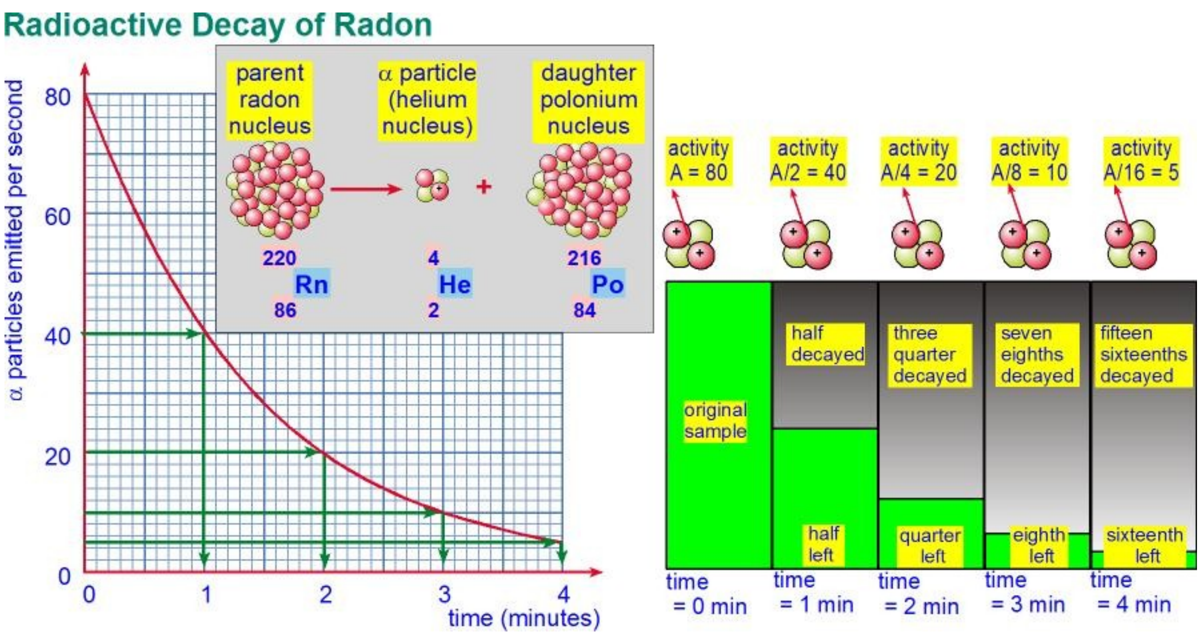
b. The mass number for the β particle is 0, as the mass of an electron is much smaller than a proton or neutron.

c. *The total number of nucleons is conserved in the reaction*. There are 234 nucleons before the reaction so there must be 234 nucleons after the reaction. The daughter nucleus of protactinium must have the 234 nucleons, so its mass number *A* must be 234.

d. The thorium nucleus contains 234 nucleons, of which 90 are protons. It must contain 234 – 90 = 144 neutrons.

e. The protactinium nucleus also contains 234 nucleons, of which 91 are protons. It must contain 234 – 91 = 143 neutrons.

Lesson Point 4: Radioactive Decay and Half Life



The diagram shows the decay of the radioactive gas radon. The nuclear reaction, the decay pattern and a graph of its activity versus time are shown.

1) The unstable parent nucleus of radon, chemical symbol **Rn**, produces a daughter nucleus of polonium, chemical symbol **Po**, by emitting an α particle.
2) Two principles can be applied to a nuclear reaction:

1. Conservation of charge: *total charge remains constant.*

a. The radon nucleus has an atomic number of 86 so there are 86 protons in the parent nucleus of radon.
b. The α particle has an atomic number of 2 so there are 2 protons in the α particle.
c. *The total charge is conserved in the reaction*. There are 86 protons before the reaction so there must be 86 protons after the reaction. The daughter nucleus of polonium must have the remaining 84 protons, so its atomic number *Z* must be 84.

2. Conservation of nucleon number: *total number of nucleons (neutrons plus protons) remains constant.*

a. The radon nucleus has a mass number of 220 so there are 220 nucleons in the parent nucleus of radon.
b. The α particle has a mass number of 4 so there are 4 nucleons in the α particle.
c. *The total number of nucleons is conserved in the reaction*. There are 220 nucleons before the reaction so there must be 220 nucleons after the reaction. The daughter nucleus of polonium must have the remaining 216 nucleons, so its mass number *A* must be 216.
d. The radon nucleus contains 220 nucleons, of which 86 are protons. It must contain 220 – 86 = 134 neutrons.
e. The α particle contains 4 nucleons, of which 2 are protons. It must contain 4 - 2 = 2 neutrons.
f. The polonium nucleus contains 216 nucleons, of which 84 are protons. It must contain 216 – 84 = 132 neutrons.
g. **The activity A** *of a sample emitting radioactive emissions is the number of particles emitted per second*.
h. The activity of a radioactive sample is *proportional to the number of undecayed nuclei in the sample*. As the sample decays, it becomes less active, i.e. it gives off fewer particles per second.
i. **The half life of a radioactive sample** *is the time taken for half the nuclei in the sample to decay or the time taken for its activity to decay to half its value*.
j. Initially the activity is 80 particles per second. After a half life of 1 minute, one half of the nuclei in the sample have decayed, leaving the other half undecayed. The activity has dropped to 40 particles per second, which is half its initial value.
k. After two half lives, a time of 2 minutes, three-quarters of the nuclei have decayed, leaving a quarter undecayed. The activity has dropped to 20 particles per second, which is a quarter of its initial value.

l. This pattern continues and shows why the sample will always be radioactive, but to a lesser and lesser degree.
m. It will take an infinite time for the process to stop.

Lesson Point 5: Nuclear Power Generation

The diagram discusses nuclear power generation.

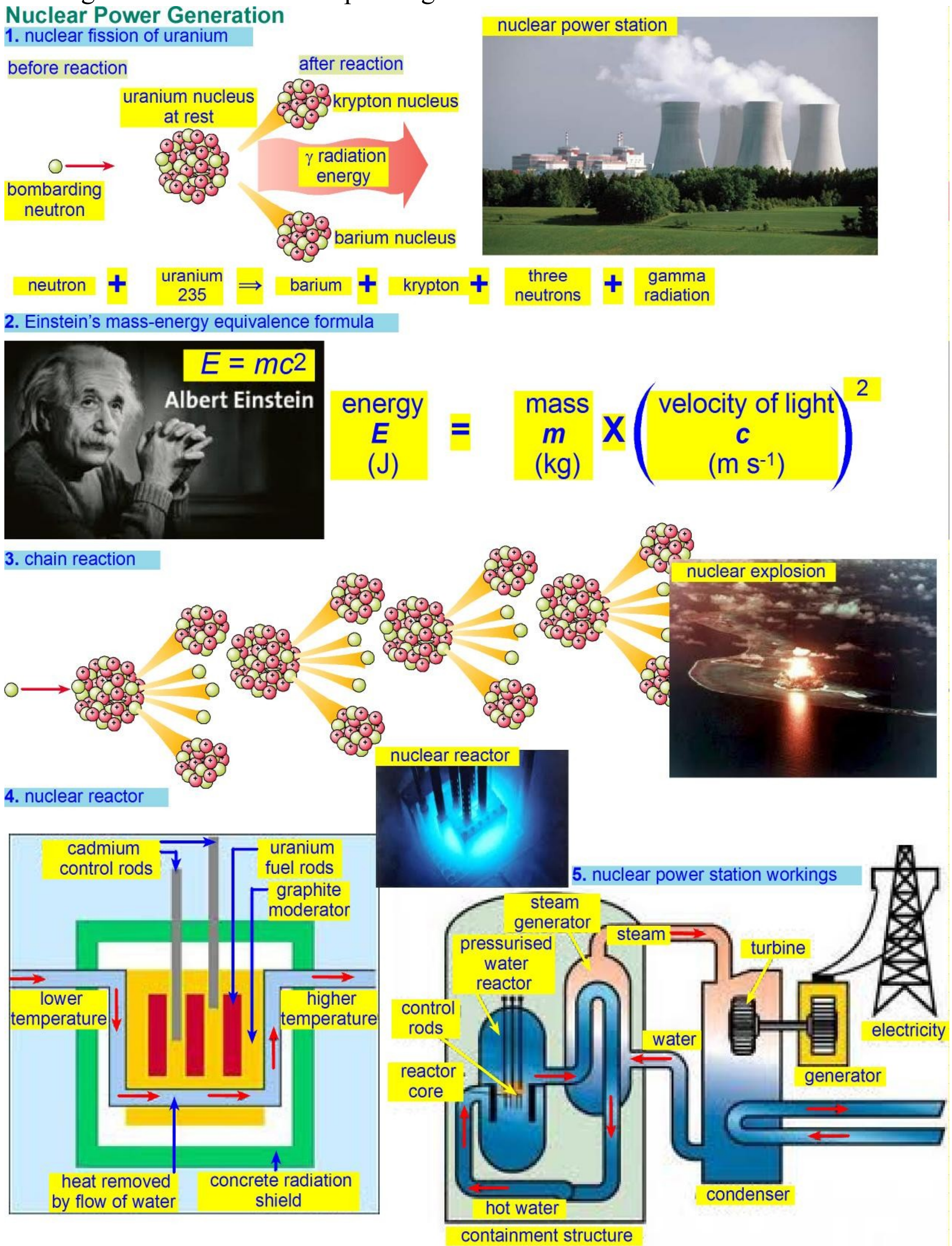


Figure 1 shows the nuclear fission reaction of uranium isotope 235.

1) Nuclear power is the use of sustained nuclear fission to generate heat and electricity.
2) Nuclear power is generated using uranium, a metal that is mined as an ore in large quantities, with Canada, Australia and Kazakhstan providing more than half of the world's supplies.

3) **Nuclear fission** *is the splitting of a large nucleus into two smaller parts.*
4) When a neutron strikes a uranium 235 nucleus, it is absorbed and the resulting nucleus becomes unstable and splits.
5) The fission products are krypton, barium, three neutrons and gamma electromagnetic energy.

Figure 2 shows Einstein's mass-energy equivalence formula.

1) In 1905, as part of his Special Theory of Relativity, Albert Einstein suggested mass and energy are equivalent.
2) Einstein's mass-energy formula is
   - $E = mc^2$ where m is the mass loss in kilograms, c is the velocity of light in metres per second = 3.00×10^8 m s^{-1} and E is the energy released in joules.
3) In the fission of uranium 235, there is a small loss of mass, as the total mass of all the particles produced in the fission reaction is slightly less than the total mass of the bombarding neutron and the uranium 235 nucleus.
4) This small loss of mass results in a large amount of energy released in the form of gamma electromagnetic wave radiation.
5) The small loss in mass in the splitting of one uranium 235 nucleus is 3.09×10^{-28} kg.
6) The amount of energy released, due to this loss of mass, is given by Einstein's mass-energy formula $E = mc^2 = 3.09 \times 10^{-28} \times (3.00 \times 10^8)^2 = 2.781 \times 10^{-11} = 2.78 \times 10^{-11}$ J to 3 sf.

Figure 3 shows a chain reaction.

1) Each time a uranium 235 nucleus splits, it releases three neutrons.
2) If at least one of those neutrons encounters another uranium 235 nucleus, then a further fission occurs.
3) This process may continue as a chain reaction, producing an uncontrolled nuclear explosion.

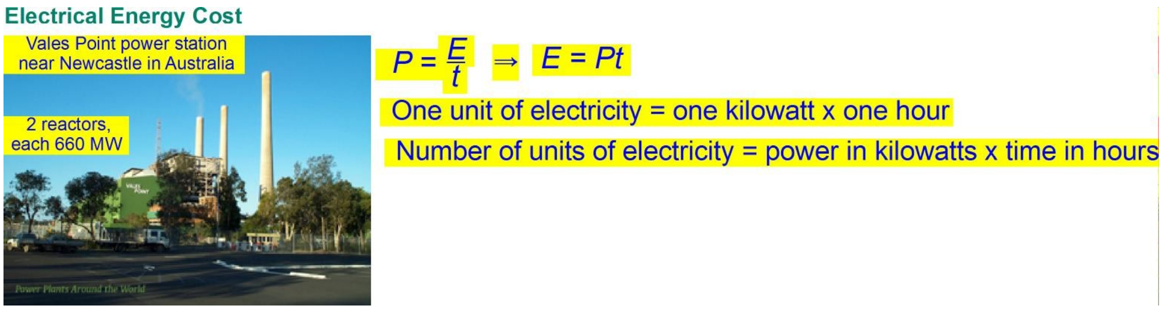
Figure 4 shows a nuclear reactor used in a nuclear power station.

1) In a nuclear reactor, the chain reaction is controlled so it takes place at a chosen steady rate.
2) The reactor consists of a core which contains natural uranium.
3) The fuel rods contain 99% uranium 238, which does not undergo fission, and 1% uranium 235, which does undergo chain reaction fission.
4) Cadmium control rods have the property of absorbing neutrons and so slow the chain reaction down or even stop it.
5) Bothe the fuel and cadmium rods are mounted in graphite.
6) The graphite is a moderator which slows the neutrons down without absorbing them.
7) The uranium 235 gives off neutrons, and the cadmium rods absorb them
8) The cadmium rods are gradually removed to start the reactor.
9) The number of cadmium rods is very carefully controlled so that exactly the right number of neutrons is free to react.
10) All the cadmium rods can be dropped into the reactor, to shut it off quickly in case of an emergency.

Figure 5 shows the workings of a nuclear power station.

1) The fission reaction produces heat energy.
2) Water is used to carry heat energy away from the reactor.
3) The steam produced drives a steam turbine which drives an electrical generator.

The diagram discusses the cost of electrical energy.



1) The nuclear power station at Vales Point near Newcastle in Australia has two reactors, each with a power output of 660 MW.
2) **Power** *is the rate at which energy is supplied.*
3) The SI unit of power is the watt (W).
4) A useful non-SI unit is the kilowatt which is 1000 W.
5) The SI unit of energy is the joule (J).
6) The commercial unit of electrical energy is the kilowatt hour (kWh), which is one kilowatt of power running for one hour.
7) The power formula is:
   - $P = \frac{E}{t}$.
   - Power = $\frac{\text{energy}}{\text{time}}$.
   - Energy is given by $P = \frac{E}{t} \rightarrow E = Pt$.
   - Energy = power x time.
   - The number of units of electrical energy = power in kilowatts x time in hours.
   - The number of units of electrical energy one reactor at Vales Point, running for a day, would supply is given by the power in kW x time in hours = 660 x 10^6 x 24 = 15.84 x 10^9 = 16 x 10^9 units of electricity to 2 sf.
   - A typical cost per unit of electricity in New Zealand is \$0.289.
   - The cost of using the electricity supplied in one day by the Vales Point reactor = number of units of electricity x cost of one unit = 15.84 x 10^9 x \$0.289 = \$4.57776 x 10^9 = 4.6 billion dollars to 2 sf.

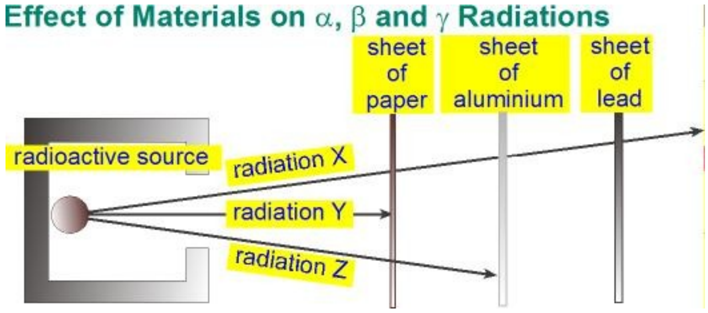
COMPUTER WORK

Log on to Live-wire Learning and answer the questions.

MODULE	First Attempt /10	Working at	Second Attempt /10	Working at
Radioactive decay – Achieved Only				
Radioactive decay				

Merit and Excellence Level Questions

Q.1. The diagram shows a radioactive source giving off the three naturally occurring radioactive emissions discovered by Rutherford. They are labelled **X**, **Y** and **Z**. Their paths are incident on three sheets of material.



a) Write into the paragraph below the appropriate word from the list given.

List: paper aluminium lead many negligible small moderate large

α particles are absorbed by ___1___, travel a ___2___ distance in air and cause a ___3___ ionisation of the air. β particles are absorbed by ___4___, travel a ___5___ distance in air and cause a ___6___ ionisation of the air. γ radiation is partially absorbed by ___7___, travels a ___8___ distance in air and causes ___9___ ionisation of the air.

b) Write into the paragraph below the appropriate word from the list given.

List: alpha beta gamma negligible small large

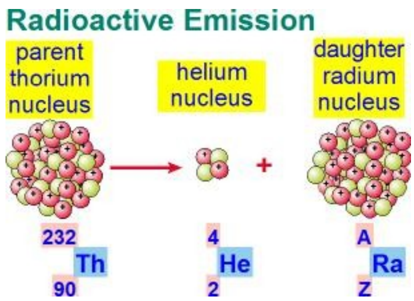
Radiation X, as it travels through the air, has ______________ absorption and produces a ______________ amount of ionisation. Radiation X is ______________ radiation.
Radiation Y, as it travels through the air, has ______________ absorption and produces a ______________ amount of ionisation. Radiation Y is ______________ radiation.
Radiation Z, as it travels through the air, has ______________ absorption and produces a ______________ amount of ionisation. Radiation Z is ______________ radiation.

Q.2. The diagram shows a natural nuclear reaction.

a) Write into the paragraph below the appropriate number from the list given.

List

2 4 88 90 92 138 140 142 228 230 232



The parent thorium nucleus has ______________ protons, ______________ nucleons and ______________ neutrons. The helium nucleus ______________ protons______________ nucleons and ______________ neutrons. The daughter radium

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nucleus has _______________ protons, _______________ nucleons and _______________ neutrons.

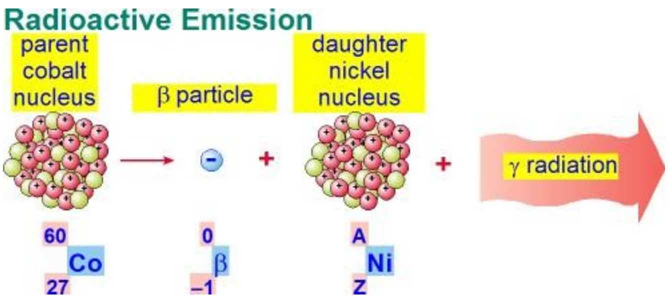
b) Write into the paragraph below the appropriate word from the list given.

List: alpha beta gamma electrons charge neutrons nucleons

The helium nucleus is an _______________ particle. For nuclear reactions, the conservation of charge principle states that the total _______________ remains constant. For nuclear reactions, the conservation of mass number principle states that the total number of _______________ remains constant.

Q.3. The diagram shows a natural nuclear reaction.

a) Write into the paragraph below the appropriate number from the list given.



List

0 1 26 27 28 29 30
31 32 33 34 59 60 61

The parent cobalt nucleus has _________________ protons, _________________ nucleons and _________________ neutrons. The β particle has _________________ protons, _________________ nucleons and _________________ neutrons. The daughter nickel nucleus has _________________ protons_________________ nucleons and _________________ neutrons.

b) Write into the paragraph below the appropriate word from the list given.

List: alpha beta gamma charge mass energy

In 1905, as part of his Special Theory of Relativity, Albert Einstein suggested mass and _______________ are equivalent. In the nuclear reaction, there is a small loss of _______________ resulting in a large amount of _______________ release in the form of _______________ radiation. The conservation of _______________ and nucleon number in the reaction, are unaffected by the release of _______________ radiation, as the _______________ loss is insignificant compared to the _______________ of a nucleon.

c) Write into the paragraph below the appropriate word from the list given.

List: electron-shells electron proton neutron nucleus

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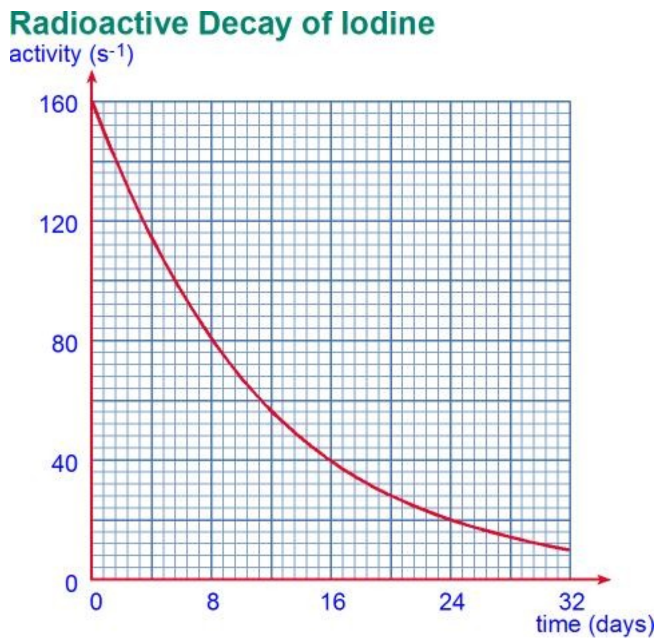
The beta particle is an ______________, from the ______________of the cobalt atom. In the nuclear reaction, a ______________in the cobalt ______________has split into a ______________and an electron.

Q.4. The diagram shows the decay of a radioactive iodine isotope. A graph is shown of the activity of the iodine versus time.



a) Write into the paragraph below the appropriate word from the list given.

List: decayed undecayed half more less second infinite

The half life of the iodine is the time taken for ______________ the nuclei in the sample to decay. The activity of the iodine is the number of particles emitted per ______________. The half life of the iodine is the time taken for its activity to decay to ______________ its value. The activity of the iodine is proportional to the number of ______________ nuclei in the sample. As the iodine decays, it becomes ______________ active. The whole life of the iodine is ______________.

b) What is the initial activity of the iodine sample?

---

c) What is the activity of the iodine sample after one half life?

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d) What is the half life of the iodine sample?

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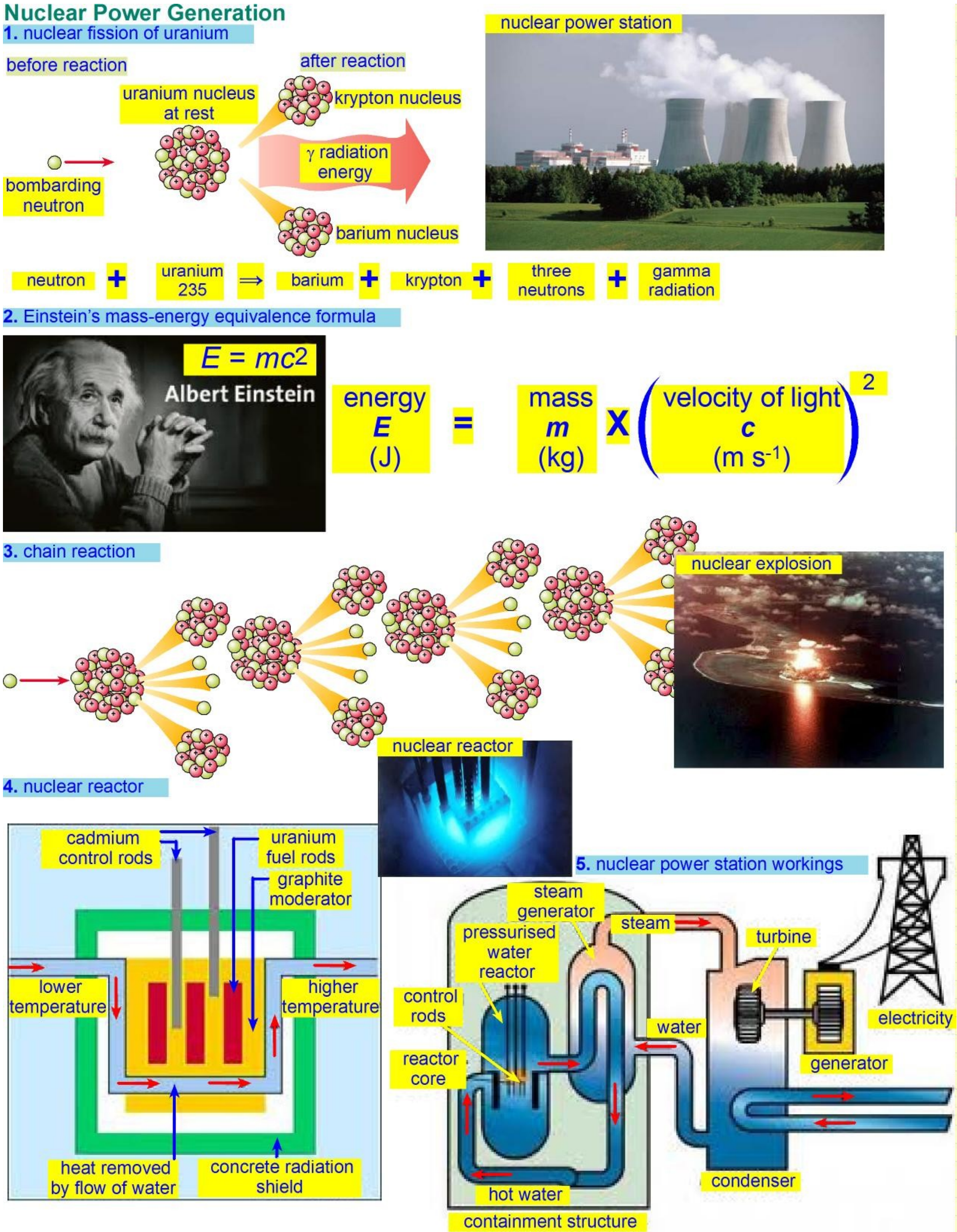
e) What is the activity of the iodine sample after two half lives?

Q.5. The diagram discusses nuclear power generation**.**



a) Write into the paragraph below the appropriate word from the list given.

List: splits fission large small heat electricity proton neutron

As shown in figure 1, nuclear power is the use of sustained nuclear ______________ to generate ______________ and ______________, by the splitting of a ______________ nucleus into two ______________ parts. When a ______________ strikes a uranium 235 nucleus, it is absorbed and the resulting nucleus becomes unstable and ______________.

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b) Write into the paragraph below the appropriate word from the list given.

List: energy mass less more alpha beta gamma neutron electromagnetic

In the fission of uranium 235 shown in figure 2, there is a small loss of ______________, as the total mass of all the particles produced in the fission reaction is slightly ______________ than the total mass of the bombarding neutron and the uranium 235 nucleus. This small loss of mass results in a large amount of ______________ released in the form of ______________ radiation which is an ______________ wave.

c) Write into the paragraph below the appropriate word from the list given.

List: one two three splits chain fission controlled uncontrolled

As shown in figure 3, each time a uranium 235 nucleus ______________, it releases ______________ neutrons. If at least ______________ of those neutrons encounters another uranium 235 nucleus, then a further ______________ occurs. This process may continue as a ______________ reaction, producing a ______________ nuclear explosion.

d) Write into the paragraph below the appropriate word or number from the list given.

List: protons neutrons control 235 238 chain slow stop moderator reactor number

As shown in figure 4, the nuclear ______________ used in the power station consists of a core which contains mainly uranium ______________ with a small amount of uranium ______________. Cadmium ______________ rods have the property of absorbing ______________ and so ______________ the ______________ reaction down or even ______________ it. The graphite is a ______________ which slows the ______________ down without absorbing them. The ______________ of cadmium rods is very carefully controlled so that exactly the right number of ______________ is free to react.

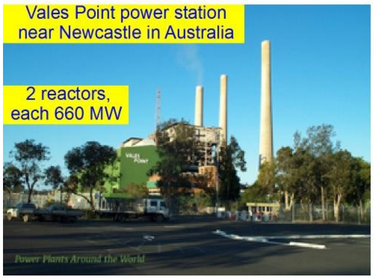
e) Write into the paragraph below the appropriate word from the list given.

List: nuclear heat water fission steam generator turbine

Figure 5 shows the workings of a nuclear power station where the ______________ reaction in the reactor produces ______________ energy. ______________ is used to carry ______________ energy away from the reactor. The ______________ produced drives a ______________ which drives an electrical ______________.

Q.6. The diagram discusses the cost of electrical energy.

Electrical Energy Cost



$P = \frac{E}{t} \Rightarrow E = Pt$

One unit of electricity = one kilowatt x one hour

Number of units of electricity = power in kilowatts x time in hours

a) Write into the paragraph below the appropriate word or number from the list given.

List:

kilowatt watt kW W Wh kWh J rate 1000 1000000 joule power time

Power is the _______________ at which energy is supplied. The SI unit of power is the _______________ which has the symbol _______________. A useful non-SI unit of power is the _______________ which is _______________ W. The SI unit of energy is the _______________ which has the symbol _______________. The commercial unit of electrical energy is the kilowatt hour which has the symbol _______________. The number of commercial units of electrical energy = _______________ in kilowatts x _______________ in hours.

Each reactor at Vales Point has a power output of 660 MW. Calculate the cost of using the electricity supplied in one hour by one of the Vales Point reactors, at a cost of \$0.289 per commercial unit.

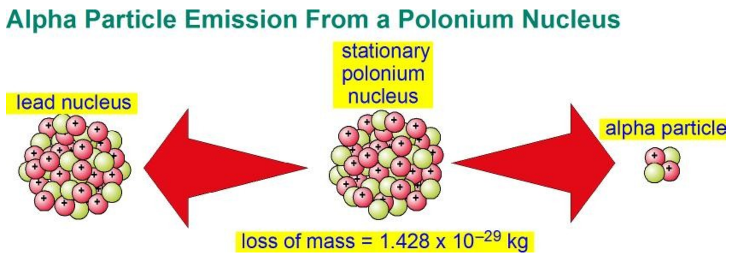
____

____

____

____

Q.7. The diagram shows a stationary polonium nucleus decaying into a lead nucleus and an alpha particle. The loss of mass in the nuclear reaction is 1.428×10^{-29} kg**.**



Calculate the energy released by the reaction due to the loss of mass. ($c = 3.00 \times 10^{8}$ m s^{-1}).

____

____

____

____

ANSWERS
1. MODELLING THE ATOM

Q.1.

a) Because the atom is mainly space.

b) Positively charged alpha particles do not take this path as they will not be attracted to a positively charged nucleus.

c) Because these positively charged particles pass close by a positively charged nucleus, they are repelled.

d) Because these positively charged alpha particles are moving head on to a positively charged nucleus.

Q.2.

John Dalton stated that an element is made of atoms and that every **element** has its own kind of **atom**. An **element** is a basic chemical which cannot be broken down into a simpler substance. An **atom** is the smallest particle of an element which can have the element's properties. Atoms bond together, to produce a **molecule** of a **compound**. The chemical **formula** for water is H_2O, showing the water **molecule** contains two atoms of **hydrogen** and one atom of **oxygen**, chemically combined.

Q.3.

a) Thomson's model is a **solid** matter atom. Thomson suggested that all **matter** should be thought of as a combination of negatively charged **electrons** and some **positively** charged matter. **Negatively** charged **electrons** are embedded in **positively** charged matter.

b) Rutherford's model is mainly **space**. His model of an atom, had a small, central, **positively** charged **nucleus**, containing nearly all the **mass** of the atom, surrounded by **electrons** in **circular** orbits.

Q.4.

a) The diagram shows 19 protons in the nucleus so the atomic number of potassium is 19.

b) The diagram shows 20 neutrons in the nucleus.

c) The diagram shows 19 protons and 20 neutrons in the nucleus, a total of 39 nucleons, so the mass number of potassium is 39.

d) The diagram shows19 protons in the nucleus. An electrically neutral atom has the same number of negatively charged electrons as positively charged protons. The potassium atom has 19 electrons.

e) The number of electrons in the first orbital shell of an electrically neutral potassium atom is 2.

f) The number of electrons in the second orbital shell of an electrically neutral potassium atom is 8.

g) The number of electrons in the third orbital shell of an electrically neutral potassium atom is 8.

h) The number of electrons in the fourth orbital shell of an electrically neutral potassium atom is 1, giving a total of 19 electrons in the orbital shells.

i) The letter of the correct representation of the potassium atom, from the key shown in the diagram is D.

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2. RADIOACTIVE DECAY

Q.1.

a) α particles are absorbed by **paper**, travel a **small** distance in air and cause a **large** ionisation of the air. β particles are absorbed by **aluminium**, travel a **moderate** distance in air and cause a **small** ionisation of the air. γ radiation is partially absorbed by **lead**, travels a **large** distance in air and causes **negligible** ionisation of the air.

b) Radiation X, as it travels through the air, has **negligible** absorption and produces a **negligible** amount of ionisation. Radiation X is **gamma** radiation. Radiation Y, as it travels through the air, has **large** absorption and produces a **large** amount of ionisation. Radiation Y is **alpha** radiation. Radiation Z, as it travels through the air, has **small** absorption and produces a **small** amount of ionisation. Radiation Z is **beta** radiation.

Q.2.

a) The parent thorium nucleus has **90** protons, **232** nucleons and **142** neutrons. The helium nucleus has **2** protons, **4** nucleons and **2** neutrons. The daughter radium nucleus has **88** protons, **228** nucleons and **140** neutrons.

b) The helium nucleus is an **alpha** particle. For nuclear reactions, the conservation of charge principle states that the total **charge** remains constant. For nuclear reactions, the conservation of mass number principle states that the total number of **nucleons** remains constant.

Q.3.

a) The parent cobalt nucleus has **27** protons, **60** nucleons and **33** neutrons. The β particle has **0** protons, **0** nucleons and **0** neutrons. The daughter nickel nucleus has **28** protons, **60** nucleons and **32** neutrons.

b) In 1905, as part of his Special Theory of Relativity, Albert Einstein suggested mass and **energy** are equivalent. In the nuclear reaction, there is a small loss of **mass** resulting in a large amount of **energy** release in the form of **gamma** radiation. The conservation of **charge** and nucleon number in the reaction, are unaffected by the release of **gamma** radiation, as the **mass** loss is insignificant compared to the **mass** of a nucleon. .

c) The beta particle is an **electron**, from the **nucleus** of the cobalt atom. In the nuclear reaction, a **neutron** in the cobalt **nucleus** has split into a **proton** and an electron.

Q.4.

a) The half life of the iodine is the time taken for **half** the nuclei in the sample to decay. The activity of the iodine is the number of particles emitted per **second**. The half life of the iodine is the time taken for its activity to decay to **half** its value. The activity of the iodine is proportional to the number of **undecayed** nuclei in the sample. As the iodine decays, it becomes **less** active. The whole life of the iodine is **infinite**.

b) The initial activity of the iodine sample is 160 particles s^{-1}.

c) The activity of the iodine sample after one half life is 80 particles s^{-1}.

d) The half life of the iodine sample is 8 days.

e) The activity of the iodine sample after two half lives is 40 particles s^{-1}.

Q.5.

a) As shown in figure 1, nuclear power is the use of sustained nuclear **fission** to generate **heat** and **electricity**, by the splitting of a **large** nucleus into two **small** parts. When a **neutron** strikes a uranium 235 nucleus, it is absorbed and the resulting nucleus becomes unstable and **splits**.

b) In the fission of uranium 235 shown in figure 1, there is a small loss of **mass**, as the total mass of all the particles produced in the fission reaction is slightly less than the total mass of the bombarding neutron and the uranium 235 nucleus. This small loss of mass results in a large amount of **energy** released in the form of **gamma** radiation which is an **electromagnetic** wave.

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c) As shown in figure 3, each time a uranium 235 nucleus **splits**, it releases **three** neutrons. If at least **one** of those neutrons encounters another uranium 235 nucleus, then a further **fission** occurs. This process may continue as a **chain** reaction, producing a **uncontrolled** nuclear explosion.

d) As shown in figure 4, the nuclear **reactor** used in the power station consists of a core which contains mainly uranium **238** with a small amount of uranium **235**. Cadmium **control** rods have the property of absorbing **neutrons** and so **slow** the **chain** reaction down or even **stop** it. The graphite is a **moderator** which slows the **neutrons** down without absorbing them. The **number** of cadmium rods is very carefully controlled so that exactly the right number of **neutrons** is free to react.

e) Figure 5 shows the workings of a nuclear power station where the **fission** reaction in the reactor produces **heat** energy. **Water** is used to carry **heat** energy away from the reactor. The **steam** produced drives a **turbine** which drives an electrical **generator**.

Q.6.

a) Power is the **rate** at which energy is supplied. The SI unit of power is the **watt** which has the symbol **W**. A useful non-SI unit of power is the **kilowatt** which is **1000** W. The SI unit of energy is the **joule** which has the symbol **J**. The commercial unit of electrical energy is the kilowatt hour which has the symbol **kWh**. The number of commercial units of electrical energy = **power** in kilowatts x **time** in hours.

b) The number of units of electrical energy supplied by one reactor at Vales Point, running for an hour, = power in kW x time in hours = 660 x 10^3 x 1 = 660 x 10^3 units of electricity. The cost of using the electricity supplied in one hour by one of the Vales Point reactors = number of units of electricity x cost of one unit = 660 x 10^3 x \$0.289 = \$1.9074 x 10^5 = \$1.9 x 10^5 to 2 sf.

Q.7. The amount of energy released, due to this loss of mass, is given by Einstein's mass-energy formula $E = mc^2 = 1.428 \times 10^{-29} \times (3.00 \times 10^8)^2 = 1.2852 \times 10^{-12} = 1.29 \times 10^{-12}$ J to 3 sf.

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