It is recommended that you take 20 minutes to complete this assessment.

## QUESTION ONE: NUCLEAR DECAY

Plutonium-239, $^{239}_{94}Pu$ is used for the production of nuclear weapons and as a fuel in some nuclear reactors. The product of its decay is Uranium-235, $^{235}_{92}U$ .

(a) Write a nuclear equation for the decay.

$^{239}_{94}Pu \rightarrow ^{235}_{92}U + ^{4}_{2}\alpha$ A/ correct mass and atomic numbers etc.

A

(b) Name the other particle that was produced as a result of this nuclear decay.

Alpha / helium nucleus / helium ion

A/ correct name

A

(c) What TWO conservation laws did you use in order to write the equation in (a)

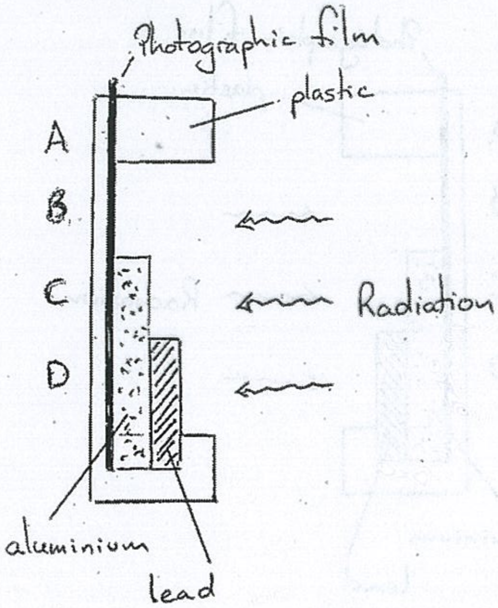
i. 'atomic mass'/'nucleon number' is conserved during nuclear decay

ii. 'proton number'/'charge' is conserved during nuclear decay

Order not important. Do not accept 'atomic number' A/one correct M/Both

AM

Radiation badges worn by staff exposed to radioactivity can determine the quantity and type of radiation emitted from the source(s) in their environment.



A/ a plausible description offered
M/ attempts to correctly describe effect of 'increasing intensity'
E/ concise, well written answer. Clear understanding of 'increasing intensity'.



Assessor's use only

(d) Describe what the photographic film will look like when exposed to increasing intensity of radiation. Explain your answer.

When photographic film is exposed to radiation a mark is created on the film where a chemical reaction has happened. As the intensity increases the number of 'marks' increases. If the film is exposed for too long or too high an intensity the film becomes 'over exposed' as no more data can be collected.

AME

(e) State the type(s) of radiation causing this exposure at each point labelled in the diagram.

A only β and γ cause exposure

B all radiation cause exposure

C only gamma causes exposure

D only (high energy) γ causes exposure

A/ three stated correctly

(f) Justify each of your answers given for part (e) showing your knowledge about the properties of each of the three types of radiation.

A α is strongly ionising and therefore easily absorbed eg. by a few centimeters of air. Therefore the α's can not get through the plastic

B there are no barriers to the radiation, so all radiation getting through the air is recorded.

C aluminium easily absorbs alpha particles, and if thick enough will stop all beta particles.

D all α and β particles are absorbed, with some weak gamma radiation. It is difficult for the badge to stop gamma radiation as several centimetres of lead would be required.

AME

M/ ... AND three EXPLAINED correctly
E/ ... AND three JUSTIFIED using knowledge about the properties of each radiation.

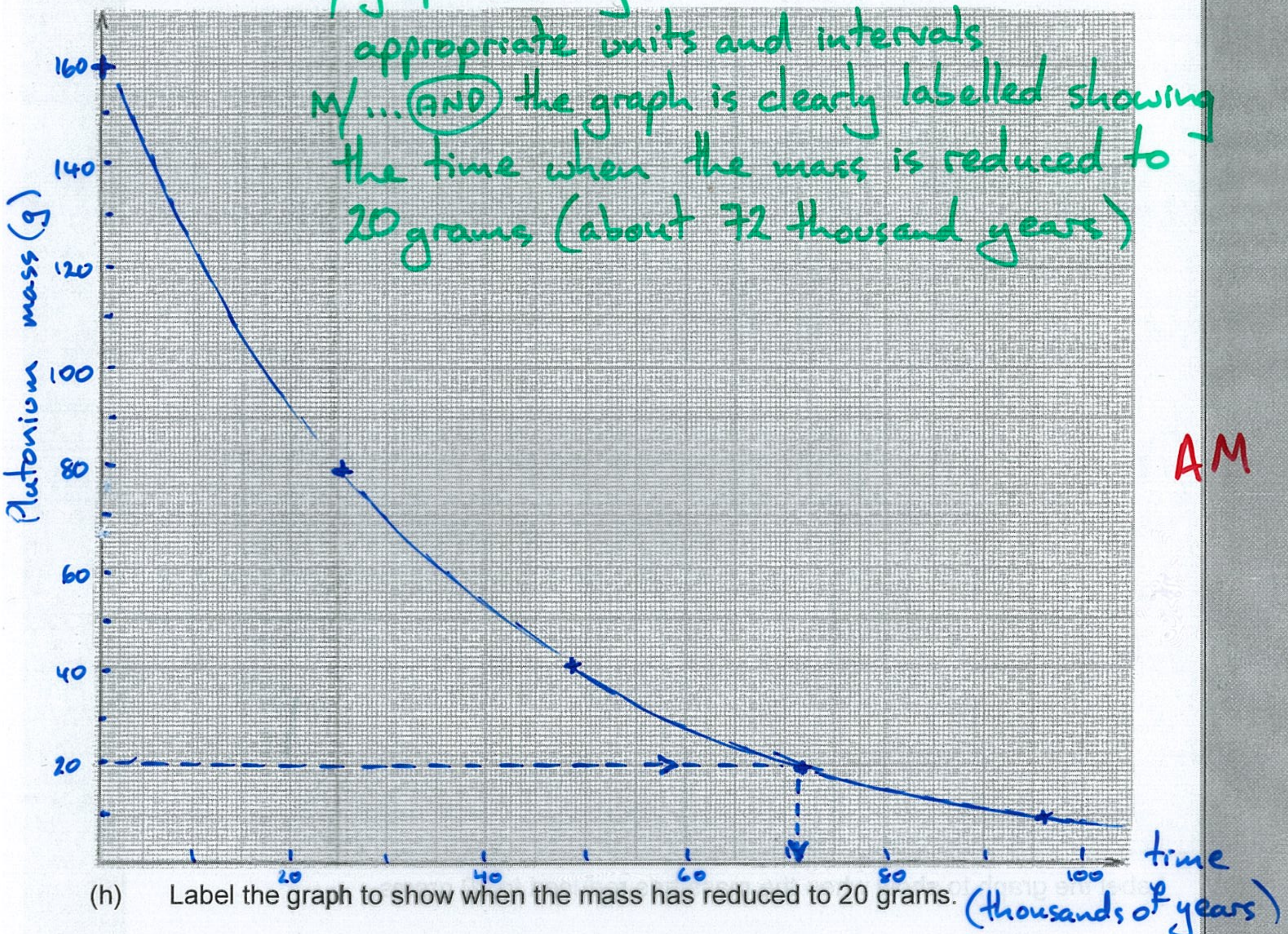
Assessor's use only

Plutonium 239 has a half life of 24,110 years.

(g) If 160 grams is manufactured and stored, show on the graph its decay up to 100,000 years.

A/ graph showing a valid trend line with appropriate units and intervals

M/ ... AND the graph is clearly labelled showing the time when the mass is reduced to 20 grams (about 72 thousand years)




AM

(h) Label the graph to show when the mass has reduced to 20 grams.

The product, Uranium-235 has a half-life of 700 million years.

(i) Calculate the time taken to reduce 160 grams of Uranium-235 to 20 grams by decay.

Mass changes by 50% with each half-life. Therefore starting with 160 to 80 to 40 to 20 is A/ three half lives (each representing 700 million years). Therefore, the time to decay is 2,100 million years!!! AM

M/ ... AND valid working and value

The radiation emitted is strongly 'ionising'.

(j) What is meant by 'ionising'?

Ionising radiation has the ability to remove/add electrons to other particles it encounters. A

A/ idea of electrons being added or removed by radiation

Assessor's use only

## QUESTION TWO: DEVELOPING MODELS FOR THE ATOM

(a) Atoms can emit electrons (negatively charged particles). Why did this fact lead to J.J. Thompson proposing, in 1907, that atoms might consist of a positive sphere with electrons scattered throughout?

If the atom is neutral and some part is negative (the electrons) then there must be a corresponding positive part.

M/ relevant statement with consequent conclusion

A/

AM

(b) Describe THREE observations that Rutherford made from his 'gold foil' alpha scattering experiment.

i Nearly all α particles went straight through the gold foil

ii About 1 in every 8000 α particles were deflected through a wide range of angles.

iii of the deflected α particles some of these were deflected directly back.

A/ two valid observations

(c) Based on the THREE observations described in part (b), explain and justify Rutherford's THREE **main** conclusions about the structure of the atom.

i nearly all of an atom is empty space with a very small nucleus because so many particles went straight through undeflected.

ii the nucleus pushes the α particles away with an electric force. Therefore, the nucleus is positively charged, because the α particle is positively charged. Like charges repel each other.

iii for the deflection directly back, the nucleus must be massive/ 'very dense'

AME

M/ Three valid observations with two valid explanations

E/ ... AND two valid justifications.

NZIP 2009

**QUESTION ONE: ATOMIC MODELS**

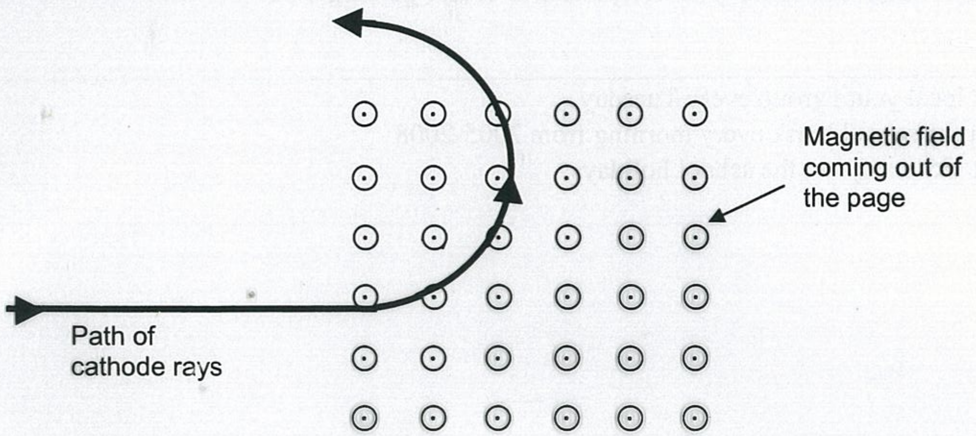
In 1830 John Dalton proposed that every substance was made up of small indivisible particles called atoms. He believed there were no objects smaller than the atom. In 1897 Thomson performed some experiments on cathode rays which were rays emitted from hot metals. These experiments led him to create a new model of the atom.

(a) Describe the atomic model proposed by Thomson.

A/ The Thomson ("plum pudding") model proposed that the atom was a positive sphere with negatively charged electrons embedded in it. The atom as a whole was neutral.

A

Thomson found that the cathode rays moved in a circular path when they were in a magnetic field.




(b) State what this experiment shows about cathode rays, and explain why the experiment showed this.

A/ The experiment showed that cathode rays were negatively charged. (OR) Cathode rays are charged because they are deflected in a magnetic field.

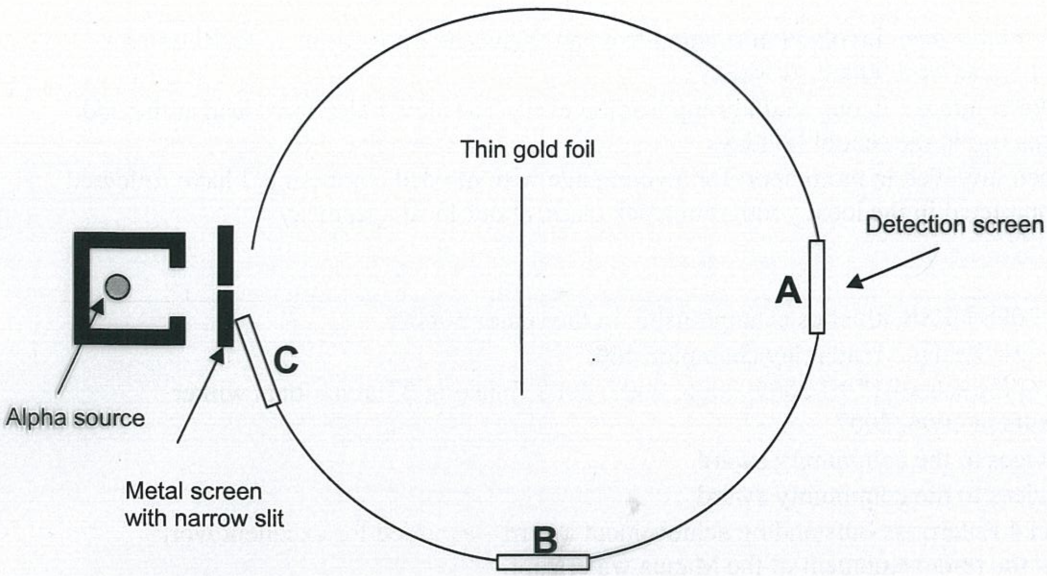
M/ ...(AND)... We know they are negative because the cathode rays turn in an anticlockwise direction while in the magnetic field. When entering the field which is out of the page, our hand rules have the force directed toward the centre of the circular path. To achieve this the ray must be negative.

argument for directions to show cathode is negative.

AM

Assessor's use only

The following diagram shows the experimental set up of Rutherford's gold foil experiment. The experiment was performed in a vacuum.




(c) Describe the function of the metal screen with the narrow slit and explain how the metal screen performs this function.

A/ The function of the metal screen is to have a narrow beam of alpha particles (all travelling in the same direction).
M/ (AND) this is achieved because alpha particles do not penetrate matter very easily, so the metal stops alpha particles and the opening lets some particles through.

AM

(d) Describe the observations that were made when the detection screen was in position A, B and C.

A: a large number of alpha particles were seen.
B: a small number of alpha particles were seen.
C: a very small number of alpha particles were seen.
A/ valid three points.

A

(e) Explain why the observations showed that the gold atoms have a very small, but heavy, positive mass inside them.

- The mass is located in a very small location, because nearly all the alpha particles went straight through the gold foil. This suggest the atom is mostly empty space.
- The mass is heavy/dense as some particles bounced straight back which suggests the nucleus was much heavier than the alpha particle.
- Alpha particles are positive as they were repelled by a positive nucleus by electrostatic forces

AME

A/ one valid explanation

M/ one complete explanations

E/ two complete explanations

Assessor's use only

Explain why the experiment had to be carried out in a vacuum.

(e) Explain why the observations showed that the gold atoms have a very small, but heavy, positive mass inside them.

Working with small numbers

A radioactive source contains 280ng of a radioisotope. The prefix n means x $10^{-9}$. Change 280ng into a mass in kg.

$280\,ng = 280 \times 10^{-9}\,g$

$= 280 \times 10^{-12} \times 10^{3}\,g$

$= 280 \times 10^{-12}\,kg$

Assessor's use only

NZIP 2009

**QUESTION TWO: RADIOACTIVE ISOTOPES USED IN MEDICAL DIAGNOSIS**

Technetium- 99m is a radioactive isotope of Technetium that is in an excited state. It is used to diagnose diseased organs.

Technetium-99m has the symbol $^{99}_{43}Tc^*$

(a) State how many protons and neutrons there are in Technetium -99m

Number of protons 43 } A/ both correct

Number of neutrons 56

A/

(b) Technetium decays by emitting a gamma ray. Complete the following nuclear reaction equation showing the decay of technetium – 99m. Show the atomic number and mass numbers of all decay products.

$$^{99}_{43}Tc^* \rightarrow {}^{99}_{43}Tc + {}^{0}_{0}\gamma$$

A/ includes correct mass and atomic numbers with chemical shorthand

A

(c) Justify the mass and atomic numbers of the decay products you stated in part (b). Include in your answer a description of

- what a gamma ray is
- quantities that are conserved in a nuclear reaction.

A/ A gamma ray is a high energy photon (or EM wave).

M/ Gamma rays have no charge so they have no atomic number ...(OR)... and they do not contain neutrons or protons so they have no mass number E/...(AND)... Therefore Atomic number and mass number are conserved in nuclear reactions, so the nucleus remaining still has the same atomic and mass numbers.

AME

Technetium-99m is created when a radioactive isotope of molybdenum emits a negatively charged beta particle.

(d) The following nuclear reaction equation shows the creation of technetium -99m. Fill in all the boxes showing the atomic and mass numbers.

$$^{99}_{42}Mo \rightarrow {}^{99}_{43}Tc^* + {}^{0}_{-1}\beta$$

A/ all numbers correct

A

NZIP 2009

Technetium-99m is created when a radioactive isotope of molybdenum emits a negatively charged beta particle.

Assessor's use only

(d) The following nuclear reaction equation shows the creation of technetium -99m. Fill in all the boxes showing the atomic and mass numbers.

$$^{99}_{42}Mo \rightarrow {}^{99}_{43}Tc^{*} + {}^{0}_{-1}\beta$$

Calculate the energy released in beta decay of a nucleus of molybdenum.

Data: molybdenum, $164.2402317 \times 10^{-27}$ kg

technetium, $164.2379959 \times 10^{-27}$ kg

beta, $0.0009044336595 \times 10^{-27}$ kg

speed of light, $c = 3.000 \times 10^{8}$ m/s

$m_{Mo} = m_{Tc} + m_{\beta} + \Delta m$

$\Rightarrow \Delta m = 164.2402317 \times 10^{-27}$ kg $- 164.2379959 \times 10^{-27}$ kg $- 0.0009044336595 \times 10^{-27}$ kg

$\Delta m = 0.001331366341 \times 10^{-27}$ kg

$E_{released} = \Delta m c^2$

$= (0.001331366341 \times 10^{-27}$ kg$) \times (3.000 \times 10^{8}$ m/s$)$

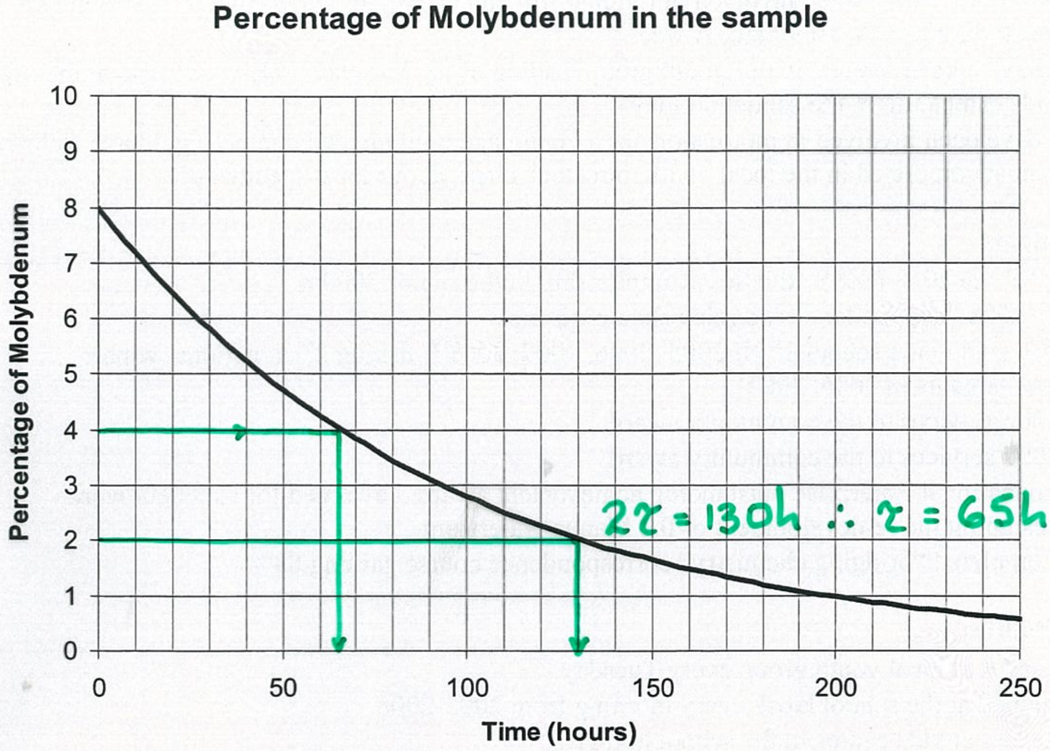
$= 1.198 \times 10^{-13}$ J (4 s.f.)

In Medical Physics explain why it is necessary for the half-life of radioistopes injected into people to have a very short time.

The half-life needs to be short enough so the activity rate will reduce quickly enough so that the patient doesn't have a harmful amount of radiation exposure.

Assessor's use only

The percentage of radioactive molybdenum found in a sample used to generate Technetium-99m was measured over several days, and the results are shown on the following graph




(e) Estimate the half life of the radioactive isotope of molybdenum.

A/ 65 hours ± 3hours

A

(f) A sample of technetium-99m can contain nuclei that have been created by beta decay at different times. In one sample Nucleus A was created from the decay of molybdenum 24 hours ago. Nucleus B was created 1 hour ago. Explain which nucleus is most likely to decay in the following 6 hours.

A/ Both

M/ nuclei are equally likely to decay in the next six hours.

E/ Whether a specific nucleus decays or not in a period of time is due to random chance and not due to the time that the nucleus has existed.

AME

Assessor's use only

Technetium-99m can be attached to a biologically active molecule so it will travel through the blood stream. A detector outside the patient's body detects the gamma rays, and uses this to form a picture of the flow of blood. Technecium-99m has a half life of 6.0 hours.

(g) Explain why radiologists use technetium-99m to image patient's blood flow, and not ruthenium-106 which decays via beta decay with a half life of 372 days. Include in your explanation a discussion of:

- The half life of technetium-99m and ruthenium-106
- The penetrating ability of the emitted radiation
- The ionisation strength of the emitted radiation

A/ • The half life of technetium-99m is shorter and so it is safer
• Gamma rays can penetrate through the body more easily than beta particles
• Gamma rays are not as ionising as beta particles

Mentions two

M/ ... AND complete explanation of the significance of one

E/ Mentions three and complete explanation of the significance of two

AME

The half life of technetium-99m is long enough in order for the radioactive isotope to travel around the body and for the doctors to be able to scan the patient, but it is short enough that the activity rate will reduce quickly so that the patient doesn't have a harmful amount of radiation exposure. Ruthenium has a much longer half-life so the patient would be exposed to large amounts of radiation over a period of years. / Technetium emits γ rays which can penetrate through many layers of tissue, so the detector outside the patients body can receive the radiation. Ruthenium emits beta particles which get absorbed more easily by the body, so not as much radiation would be able to reache the detector. / Gamma rays are weakly ionising so they do not do as much damage to tissue as beta particles that ionise atoms more easily. So technetium 99 would do less damage than ruthenium 106.

NZIP 2008



Assessor's use only

It is recommended that you take 20 minutes to complete this assessment.

**QUESTION ONE: ATOMIC MODELS**

(a) Describe the atomic model proposed by J J Thomson in 1904.

Thomson described an atom as being a cloud of positive charge with negative electrons embedded in it.

A

In 1909 Ernest Rutherford tested Thomson's model of the atom. He fired alpha particles though a very thin gold foil.

(b) Describe what an alpha particle is.

OR

An alpha particle is a helium nucleus, made up of 2 protons and 2 neutrons. It is positively charged, (because the helium atom would have lost two electrons to become a helium nucleus.) A/ positively charged M/ helium nucleus

AM

(c) Most of alpha particles passed through the gold foil without any deflection. State what feature of Rutherford new model of the atom provides an explanation for this observation.

For most alpha particles to pass through the gold foil without any deflection would require the atom to be mostly empty space.

A/ empty space

A

(d) Explain how Rutherford's experiment shows that atoms have **small positively charged** nucleus.

For the nucleus to be small most alpha particles passed through the foil undeflected, indicating that the mass is concentrated into a small volume. For the nucleus to be positive a few alpha particles bounced back in the original direction. Since the alpha particles were positively charged and like charges repel, then the nucleus was positive.

A/ either correct M/ both correct



AM

Assessor's use only

**QUESTION TWO: RADIOACTIVITY**

The diagram shows a Geiger counter. It is a device used to measure radiation from unstable atoms.

When the Geiger counter is placed in a room without any radioactive sample it registers radioactivity.

(a) Name this activity and explain why.

Name Background radiation A/ background radiation

Explanation Some materials such as rocks/minerals/gases cosmic rays in nature emit radiations.

M/... and explanation correct.

AM

A small sample of radioactive material is brought closer to Geiger counter. It detects alpha, beta and gamma radiations from the sample material.

(b) State how the alpha radiation from the beam can be filtered without affecting the beta or gamma radiation. Explain your answer.

Using a thin non-metallic barrier, like paper, between the source and Geiger counter will absorb alpha radiation without affecting the beta or gamma radiation. This is because alpha particles have a very low penetrating power, so they are unable to penetrate the paper.

A/ names an appropriate barrier

M/... and valid explanation given

AM

Assessor's use only

(c) Explain why small doses of gamma radiation are less harmful than small doses of beta radiation, even though gamma radiation is more penetrating.

Gamma rays pass through the body with little interaction and will do little damage. Whereas Beta radiation is more strongly ionising and will damage cells along its path until its energy is absorbed. A/ Part of answer correct but no wrong info.

M/ Either answer correct E/ Both answers correct

AME

(d) Radon emits alpha particles. Radon can be held in the hand without any harm. If it is inhaled it is very dangerous. Explain why.

Alpha particles are usually stopped by the skin outside the body and alpha have very low penetrating ability through skin. Whereas inside the body alpha particles come in contact with soft tissue causing ionisation of the cells i.e. damaging them, which is why they are harmful.

AME

A/ Mentions skin as a barrier

M/ ... and low penetration ability/power
OR easily absorbed by cells of soft tissue when inhaled causing damage

E/ Fully mentions both explanations

Assessor's use only

NZIP 2008

## QUESTION THREE: RADIOACTIVE DECAY

Strontium 90 (Sr) is a radioactive substance, which has 52 neutrons per atom. It decays to Yttrium 90 (Yt), which has 51 neutrons in each atom.

(a) Write a nuclear equation to show the decay of strontium 90 to Yttrium 90. Include the mass numbers and atomic numbers in your equation.

$$^{90}_{38}Sr \rightarrow {}^{90}_{39}Yt + {}^{0}_{-1}\beta \text{ OR } {}^{0}_{-1}e$$

A/ correct symbols with mass and atomic numbers correct only for Sr and Yt.

M/ correct equation

AM

The half life of Strontium 90 is about **29 years** and it decays into Yttrium 90.

Yttrium 90 is also radioactive and is a beta particle emitter with a half-life of **2.67 days**.

(b) Discuss the amount of Yttrium that would be present in the above example after the Strontium had been decaying for the first **8 days**.

Very little Yttrium 90 is present as its half life is very short compared to that of Strontium 90, because very little strontium would decay in 8 days and in that time any Yttrium that did form would have had three half lives of decay. A/

M/ mentions 'no' Yt is there because of small $T_{\frac{1}{2}}$ E/ complete explanation

AME

A radioisotope of krypton has a half-life of 3.0 s. A sample of krypton contains 1024 x $10^{24}$ undecayed atoms.

(c) Calculate how many undecayed atoms will remain after half a minute.

30 seconds = 10 half-lives of krypton

$\frac{1}{2^{10}} \times (1024 \times 10^{24}) = 1.0 \times 10^{24}$ undecay atoms

OR

1024 → decay → 512 → 256 → 128 → 64 → 32 → 16 → 8 → 4 → 2 → 1

ten decays

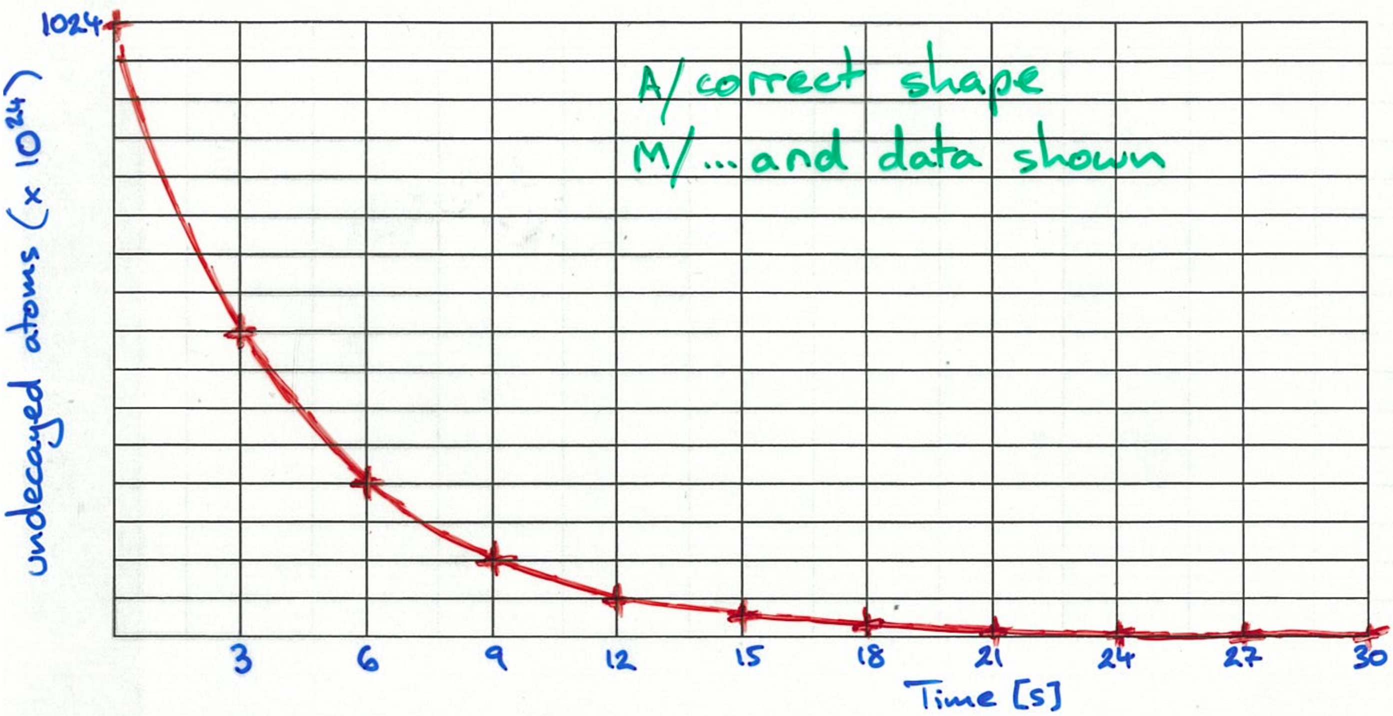
A/ 10 half-lives

M/ valid working and answer

AM

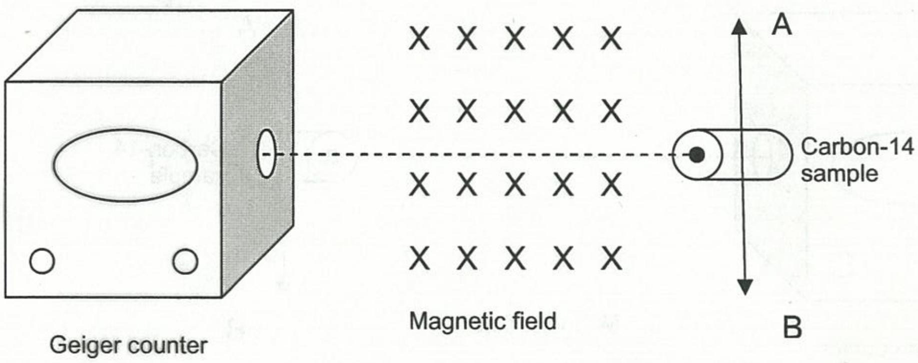
Assessor's use only

(d) Use the information in question (c), to sketch a graph on the axes below to show how a sample of krypton would change over the half-minute period.




AM

Carbon -14 emits beta particles. A sample of carbon-14 is placed near a Geiger counter. When a magnetic field is set up in the space between the carbon-14 sample and the Geiger counter, the count rate reduces almost to zero. The direction of the magnetic field is **into the page**, as shown in the diagram below.




When the carbon-14 sample is moved to one end of the line AB, the count rate increases back to its original level.

(e) State in which direction (towards A or towards B) the carbon-14 sample must be moved in order to increase the count back to its original level. Explain your answer.

Direction ____________________

Explanation ____________________

Nuclear Reactions

a. Compare and contrast a 'fission reaction' with a 'fusion reaction'. Your answer should include comments about both the reactants and the products.

In a Fission Reaction the reactants have a larger nucleus and a particle such as a neutron. The interaction between these reactants makes the large nucleus to split into two or more smaller product nuclei.
In a Fusion Reaction the reactants are two relatively small nuclei which fuse together to form one product nucleus.

b. The SONGS nuclear power plant in Southern California generates 2,200MW of power. Uranium-235 as a fuel provides $2.724 \times 10^{-11}$J during a reaction forming caesium-137 and rubidium-95

1. Calculate the minimum mass of U-235 used every hour, where the mass of an atom of U-235 is $390.3 \times 10^{-27}$ kg.

To produce $2{,}200 \times 10^6$ W, then in one hour the energy released is $(2{,}200 \times 10^6 W) \times (60\ min/hr \times 60\ sec/min) = 7.92 \times 10^{12}$ J. So the number of reactions to occur to generate this energy is $\frac{7.92 \times 10^{12} J}{2.724 \times 10^{-11} J} = 2.907... \times 10^{23}$ reactions.
Since each reaction involves one U-235 atom, then the minimum mass required is $(2.907... \times 10^{23}\ reactions) \times (390.3 \times 10^{-27}\ kg/reaction)$
$= 0.1135$ kg (4 s.f.)

2. Explain why in practice a greater quantity of U-235 would be used per hour.

This mass value assumes all the energy generated by the reaction is changed into useful electrical energy as output from the power plant. No process can be 100% efficient, so this can never happen. More uranium would need to be used to generate enough useful energy to compensate for what is wasted.

Assessor's use only

(e) State in which direction (towards A or towards B) the carbon-14 sample must be moved in order to increase the count back to its original level. Explain your answer.

Direction Towards B / Down / ↓ A/towards B

Explanation Beta particles are negatively charged, also the direction of the magnetic field is into the page, therefore the magnetic force causes an upward deflection. So the source must be moved down.

M/...and β deflected upwards

E/... with full explanation

AME

| | A | M | E |
|---|---|---|---|
| | /13 | /10 | /4 |