Nuclear Decay

1. Protactinium has a half-life of 70 s. A sample of protactinium is prepared and monitored over a period of time. Which of the following statements is correct?

A The activity of the protactinium will be zero after 140 s.

B The activity of the protactinium will be 25% of its initial value after 140 s.

C The activity of the protactinium will be 12.5% of its initial value after 280 s.

D The activity of the protactinium will never become zero.

(Total 1 mark)

2. Radioisotopes are often used for medical applications. ^{131}I is a β^{-}-emitter, and can be used to treat an overactive thyroid gland. When a small dose of ^{131}I is swallowed, it is absorbed into the bloodstream. It is then concentrated in the thyroid gland, where it begins destroying the gland's cells.

(a) Patients are advised that radiation detection devices used at airports may detect increased radiation levels up to 3 months after the treatment. Explain how it is possible for the activity of the ^{131}I to be detected outside the body.

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(2)

(b) (i) The half-life of ^{131}I is 8 days. What fraction of the original number of iodine atoms will have decayed after a period of 24 days?

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Fraction = ...

(2)

(ii) Doctors wish to prescribe a sample of ^{131}I of activity 1.5 MBq. The sample is prepared exactly 24 hours before it is due to be swallowed by the patient. Calculate the activity that the sample should have when it is prepared.

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Activity = ... MBq

(3)

(Total 7 marks)

3. Ionisation smoke detectors contain a small amount of the radioactive isotope americium. ^{241}Am is an α-emitter. It has a half-life of 432 years, and the activity from the source in a new smoke detector is about 3.5×10^4 Bq.

(a) Explain why the radiation produced by a smoke detector does not pose a health hazard.

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(1)

(b) (i) Complete the nuclear equation for the decay of americium.

$$^{241}_{\dots\dots}\text{Am} \rightarrow {}^{\dots\dots}_{93}\text{Np} + {}^{\dots\dots}_{\dots\dots}\alpha$$

(2)

(ii) Using data from the table, calculate the energy, in MeV, of α-particles released when a nucleus of americium-241 undergoes alpha decay.

Nuclide	**Mass/u**
Am	241.056 822
Np	237.048 166
α-particle	4.002 603

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Energy = ... MeV

(3)

(c) An ionisation smoke detector is sold with the guarantee that it "lasts a lifetime". Comment on the appropriateness of this guarantee, based on its use of americium-241.

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(1)
(Total 7 marks)

4. A student is asked: “What is meant by background radiation?”
She writes: “It is the radiation produced by the rocks in the ground.”
This answer is

A correct

B incorrect – rocks do not produce radiation

C incomplete

D incorrect – this radiation would not be ionising

(Total 1 mark)

5. Smoke detectors contain an alpha emitting source.

(a) Describe how you would determine whether this radioactive source emits alpha particles only.

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(4)

(b) State why smoke detectors do not provide a radiation risk in normal use.

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(1)
(Total 5 marks)

6. Potassium-40 ($_{19}$K) is unstable.

(a) Calculate the binding energy per nucleon for potassium-40.
Nuclear mass of potassium-40 = 39.953548 u
Mass of one neutron = 1.008 665 u
Mass of one proton = 1.007 276 u

Binding energy per nucleon = ...

(6)

(b) Explain what is meant by the random nature of nuclear decay.

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(1)

(c) Scientists have worked out the age of the Moon by dating rocks brought back by the Apollo missions. They use the decay of potassium-40 to argon-40. The half-life of potassium-40 is 1.3×10^9 years.

(i) Show that the decay constant of potassium-40 is about $5 \times 10^{-10}\ y^{-1}$.

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(1)

(ii) In one rock sample the scientists found 0.84 μg of argon-40 and 0.10 μg of potassium-40.

Calculate the age of the rock sample in years.

Age of rock = ...

(4)

(Total 12 marks)

7. A satellite uses a radium-226 source as a back-up power supply. Radium-226 is an alpha particle emitter.

(a) The satellite requires a back-up power of 55W. Each alpha particle is emitted with an energy of 7.65×10^{-13} J. Show that the activity of the source must be about 7×10^{13} Bq.

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(2)

(b) Radium-226 has a half-life of 1620 years. Show that its decay constant is about 1.4×10^{-11} s^{-1}.
1 year = 3.15×10^{7} s

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(2)

(c) Hence determine the number of radium-226 nuclei that would produce the required activity.

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Number of nuclei = ...

(2)

(d) Calculate the mass of radium-226 that would produce a power of 55W.
226 g of radium-226 contains 6.02×10^{23} nuclei.

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Mass = ...

(2)

(e) In practice this mass of radium-226 produces more than 55W of power. Suggest a reason why.

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(1)
(Total 9 marks)

8. Recently, some old human skulls have been found in Mexico. Their age has been established using radiocarbon, ^{14}C, dating.

(a) When a ^{14}C nucleus decays, it emits a β-particle. State how the composition of the nucleus changes as a result of the decay.

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(1)

(b) When examining a small sample of one of these old skulls, scientists found that 2.3×10^{-11} % of the carbon was ^{14}C, whereas in recent skulls this proportion is 1.0×10^{-10} %.

(i) Calculate the age of this old skull.

Half-life of ^{14}C = 5730 years

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Age = ...

(3)

(ii) Give one reason why the value you calculated above may be inaccurate.

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(1)

(iii) Recent bones are dated using the decay of ^{210}Pb, which has a half-life of 21 years. Explain why ^{210}Pb is more suitable than ^{14}C for dating recent bones.

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(1)
(Total 6 marks)

9. PET (positron emission tomography) scanning is often used to see how cancers are responding to therapy. It requires a radioactive isotope which emits positrons. A positron soon meets an electron and annihilates. The resulting photons can be detected and an image produced. An isotope of fluorine $^{18}_{9}\mathrm{F}$ can be used as it can be added to a glucose molecule. The patient is given a glucose drink containing this fluorine isotope which will then be absorbed by the cancer.

(a) The fluorine isotope is produced by bombarding an isotope of oxygen $^{18}_{8}\mathrm{O}$ with a high energy proton. Write a nuclear equation for this process.

.... $\longrightarrow$ ....

(3)

(b) The protons are typically given an energy of 19 MeV. Briefly suggest how this might be achieved.

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(2)

(c) Fluorine $^{18}\mathrm{F}$ emits positrons and has a half-life of 110 minutes. Explain the meaning of half-life and suggest why 110 minutes is suitable for this application.

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(3)

(d) Two identical photons are produced when an electron meets a positron. Calculate the wavelength of each photon.

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(4)

(e) Detectors placed on opposite sides of the patient detect these photons and can then accurately predict the precise location of the positron annihilation within the patient.

Explain why the two photons must be emitted in opposite directions.

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(2)
(Total 14 marks)

10. As a beta-minus particle travels through air it causes ionisation.

(a) Describe how the beta particle produces ionisation.

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(1)

(b) Explain how the amount of ionisation determines a beta particle's range in air.

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(3)

(c) Explain why, towards the end of its range, a beta particle will ionise more molecules per unit length than at the beginning of its range.

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(2)

(Total 6 marks)

11. (a) Radioactivity involves the *spontaneous* emission of *radiation* from *unstable* nuclei.

Explain the meaning of the words in italics as they apply to the process of radioactivity.

Spontaneous ....

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Radiation ....

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Unstable ....

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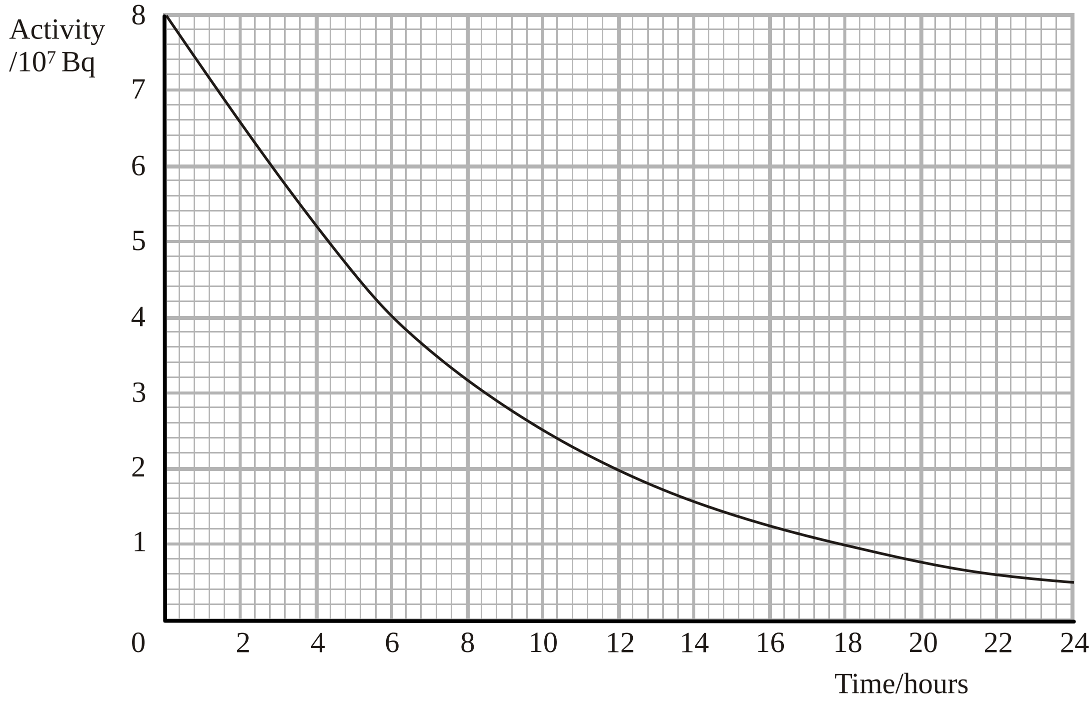
(3)

(b) The graph shows how the activity of a sample of the radioisotope technetium, which is used extensively in medicine, varies with time.



(i) Use the graph to determine the half-life of technetium.

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Half-life = ...

(2)

(ii) Hence calculate the decay constant for technetium.

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Decay constant = ...

(1)

(iii) Determine the number of technetium atoms remaining in the sample after 24 hours.

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Number of atoms = ...

(2)
(Total 8 marks)

12. (a) 'Radioactivity is a **random process**.' Explain what is meant by a random process in this context.

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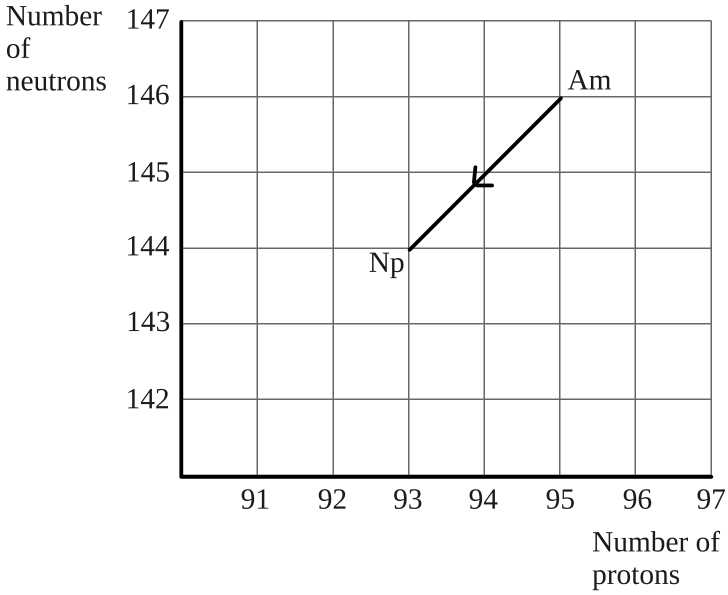
(1)

(b) The graph shows what happens to the numbers of neutrons and protons when americium (Am) decays into neptunium (Np).



Give the nuclear equation for this decay.

$\longrightarrow$

(3)

(c) Describe an experiment, involving absorption, to demonstrate that a given radioisotope emits beta radiation and no other. Include a diagram of the experimental arrangement you would use.

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(5)
(Total 9 marks)

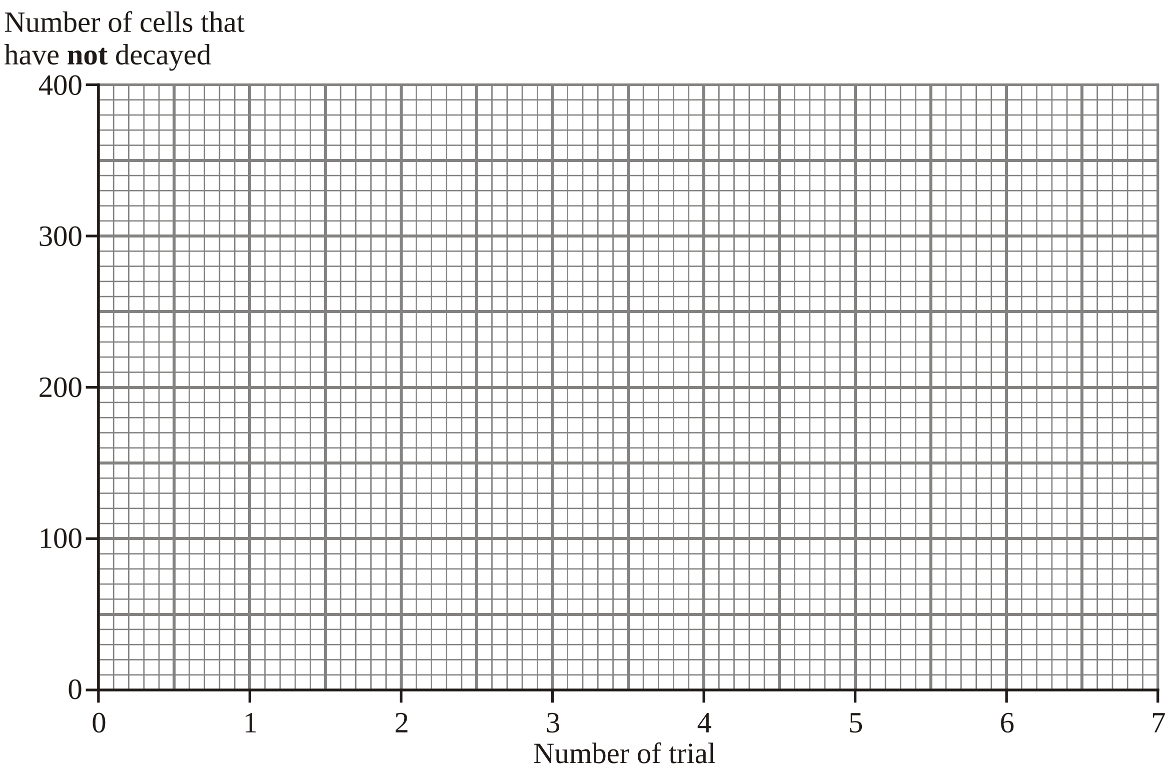
13. A student uses a computer program to model radioactive decay. The program draws a grid of 300 cells on the computer screen.

A letter can be generated at random in each cell. If a vowel (a, e, i, o, u) is generated, the cell is considered to have 'decayed' and is not available for the next trial of the decay process.

The table shows the number of the trial along with the number of cells which have **not** decayed.

Number of trial	Number of cells that have **not** decayed
0	300
1	242
2	196
3	158
4	128
5	103
6	83

(i) On the grid below, plot these data and draw the line of best fit through your points.



(2)

(ii) What is meant by the term **half-life** of a radioactive nuclide?

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(iii) Use your graph to find the 'half-life' in terms of the number of trials of this computer model of radioactive decay.

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Half-life = ...trials

(3)

(iv) In what way is this model **similar** to radioactive decay?

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(1)

(v) In what way is this model **different** from radioactive decay?

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(1)
(Total 7 marks)

14. In April 1986 an explosion destroyed one of the reactors at Chernobyl Nuclear Power Station. In the accident, radioisotopes were scattered over the surrounding area and many were carried large distances by the wind. The contamination included isotopes of strontium, iodine, caesium and plutonium.

Data on these isotopes are shown below:

Isotope	Proton number	Half-life	Particles emitted
^{90}Sr	38	28 years	β
^{131}I	53	8.1 days	β, γ
^{134}Cs	55	2.1 years	β, γ
^{137}Cs		30 years	β, γ
^{239}Pu	94	24 000 years	α, γ
^{240}Pu		6600 years	α, γ

Fill in the missing proton numbers.

(1)

The fuel for the power station originally consisted of uranium ($^{235}_{92}U$ and $^{238}_{92}U$).

(i) Name the process which produced strontium and caesium.

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(ii) Suggest how plutonium was formed in the nuclear reactor.

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(2)

In **June** 1986, the area around the power station was still dangerously contaminated, with so much ^{137}Cs in the ground that it emitted 1.5×10^6 Bq m^{-2}. Calculate the emission rate which would be recorded today from this same ground, stating any assumptions which you make.

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Emission rate = ...Bq m^{-2}

Assumption: ……………………………………………………………………………..

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(4)

Explain which of the scattered isotopes would no longer be of concern today.

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(2)

Some politicians say that the Chernobyl accident happened so long ago that it is no longer dangerous to live in the area. Comment on this statement.

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(2)

(Total 11 marks)

15. (a) Name two sources of background radiation.

1 ....

2 ....

(2)

(b) (i) A student is doing an experiment using radioactive material. She uses a counter to record the total count. Her teacher points out that she has forgotten to measure the background count rate. Describe the procedure the student should follow. You must mention any additional equipment she might need to use.

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(4)

(ii) Why might it have been unnecessary to measure the background count rate?

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(1)
(Total 7 marks)

16. (a) (i) Carbon has two important isotopes, ${}^{12}_{6}\text{C}$ and ${}^{14}_{6}\text{C}$. Carbon-14 is unstable but carbon-12 is stable.

What is meant by saying that carbon-12 is stable?

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(1)

(ii) Carbon-14 is formed in the atmosphere when a particle ${}^{1}_{0}\text{X}$ collides with an atom of nitrogen.

Complete the equation to show the missing nucleon and proton numbers:

$${}^{14}_{7}\text{N} + {}^{1}_{0}\text{X} \rightarrow {}^{14}_{6}\text{C} + {}^{\cdots\cdots\cdots}_{\cdots\cdots\cdots}\text{Y}$$

(1)

(iii) Identify the particles X and Y.

X = ... Y = ...

(2)

(b) (i) The half-life of carbon-14 is 5568 years. Show that the decay constant of carbon-14 is about 4×10^{-12} s^{-1}. (You may assume 1 year = 3.2×10^{7} s.)

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(2)

(ii) A sample of carbon-14 has an activity of 16 counts min^{-1}. Calculate the number of nuclei of carbon-14 in this sample.

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Number of nuclei = ……………………………

(2)
(Total 8 marks)

17. The first artificially produced isotope was the isotope phosphorus $^{30}_{15}P$. This was formed by bombarding aluminium Al with *α*-particles.

(a) (i) Complete the equation to show the missing nucleon and proton numbers:

$$^{\cdots\cdots}_{\cdots\cdots}Al + {}^{\cdots\cdots}_{\cdots\cdots}\alpha \rightarrow {}^{30}_{15}P + {}^{1}_{0}n$$

(2)

(ii) $^{30}_{15}P$ decays to a stable isotope of silicon $^{30}_{14}Si$ by the emission of a further particle, X. Complete the following equation to show the missing nucleon and proton numbers:

$$^{30}_{15}P \rightarrow {}^{30}_{14}Si + {}^{\cdots\cdots}_{\cdots\cdots}X$$

Suggest what the particle X is.

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(2)

(b) The half-life of the radioactive isotope of phosphorus $^{30}_{15}P$ is 195 seconds. Give the meanings of the terms **half-life** and **isotope**.

Half-life ....

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Isotope ....

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(3)

(c) Atoms which emit α- or β-particles usually emit γ-rays as well. Explain why this occurs.

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(1)
(Total 8 marks)

18. Radioactive isotopes emitting gamma radiation can be used to preserve food. The food is exposed to the radiation which kills most of the bacteria that occur naturally.

Why is gamma radiation used in this process rather than alpha or beta?

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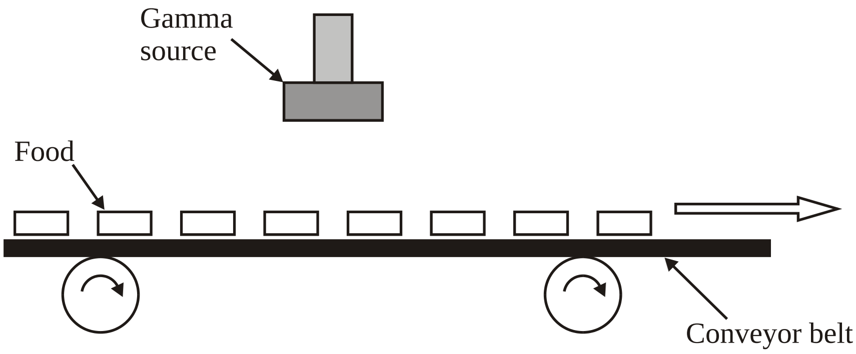
(1)

The food is passed on a conveyor belt under a radiation source.



State **two** factors which control the amount of radiation reaching each item of food.

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(2)

A thick wall surrounds the irradiation room to prevent the radiation escaping. Suggest a suitable material and thickness for this wall.

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(2)

Many consumers are worried about irradiated food, as they wrongly believe that this makes it become radioactive. Food does, however, contain a small level of naturally occurring radiation. Name something other than food that is also a source of natural radiation.

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(1)
(Total 6 marks)

19. **Carbon clock could show the wrong time**

This was the headline of a news report in Physics Web in May 2001 about some stalagmites found in a cave in the Bahamas.

Stalagmites are found in limestone caves and are long, thin rocks formed by the deposition of calcium carbonate from solution. The stalagmites in the news report are a half-metre long. They contain atoms of the radioactive isotope carbon-14, which has a half-life of 5730 years. The decay of carbon-14 can be used to determine the age of objects. This process is called radiocarbon dating.

In one part of the stalagmites, $\frac{255}{256}$ of the carbon-14 atoms have decayed.

Determine the age of this part of the stalagmite.

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Age = ...

(3)

Some parts were formed much more recently. How would this affect their carbon-14 concentration?

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(1)

However, scientists have found that the level of carbon-14 when the oldest parts of the stalagmites were formed was twice the modern level. Discuss the effect on the validity of radio-carbon dating.

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(3)
(Total 7 marks)

20. After the first bounce of a bungee jump, a jumper oscillates on the end of the rope. These oscillations have an initial amplitude of 4.0 m and a period of 5.0 s.

The velocity of the jumper is given by $v = -\omega A \sin \omega t$. Show that the maximum velocity of the jumper is about 5 m s^{-1}.

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(2)

Explain why the tension in the rope and the jumper’s weight must be balanced when the velocity of the jumper is maximum.

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(2)

The time period T of the oscillations is given by $T = 2\pi\sqrt{\frac{m}{k}}$.

Calculate the stiffness k for the rope. The jumper has a mass m of 70 kg.

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k = ...

(2)

Verify, with a suitable calculation, that the rope is never slack during these oscillations.

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(3)

Briefly describe the oscillations experienced by the jumper during the minute after the first bounce.

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(1)

(Total 10 marks)

21. A smoke detector contains a small radioactive source. A typical source contains 1.2×10^{-8} g of americium-241, which has a half-life of 432 years. Show that the decay constant of americium-241 is approximately 5×10^{-11} s^{-1}.

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(2)

Calculate the number of nuclei in 1.2×10^{-8} g of americium-241, given that 241 g contains 6.0×10^{23} nuclei.

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Number of nuclei = ...

(1)

Hence calculate the activity of 1.2×10^{-8} g of americium-241.

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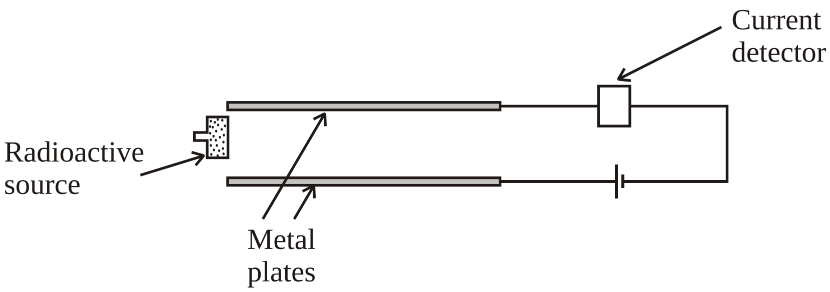
Activity = ...

(2)

The diagram below shows the principle of the smoke detector.



Radiation from the source ionises the air between the plates, and a small current is detected. If smoke enters the detector, the ions 'stick' to the smoke particles, reducing the current and triggering an alarm.

Americium-241 is an alpha emitter. Explain why an alpha emitter is a suitable source for this apparatus.

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(2)

Discuss other features of this americium sample which make it a suitable source for the smoke detector.

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(3)
(Total 10 marks)

22. (a) Explain what is meant by the term binding energy.

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Iron has the highest binding energy per nucleon of any nucleus. What does this tell you about an iron nucleus?

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(3)

(b) Carbon-14, ${}^{14}_{6}\mathrm{C}$, is unstable and decays by β^- emission to nitrogen, N. Write a full nuclear equation for this decay.

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(3)

Carbon-14 has a half-life of 5730 years. Living organisms contain approximately 100 atoms ${}^{14}_{6}\mathrm{C}$ for every 10^{20} atoms of stable carbon-12, ${}^{12}_{6}\mathrm{C}$. Estimate the age of a fossil which is found to contain approximately 12 atoms of ${}^{14}_{6}\mathrm{C}$ for every 10^{20} atoms of ${}^{12}_{6}\mathrm{C}$.

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(2)
(Total 8 marks)

23. An airport decides to use γ-radiation to examine luggage.

How are γ-rays dangerous to people?

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(2)

Suggest a material which could be used for the shielding of airport staff, and the minimum thickness required.

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(2)

Why is α radiation not used to examine luggage?

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(1)

Explain why air travellers are exposed to increased doses of background radiation.

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(2)
(Total 7 marks)

24. What are isotopes?

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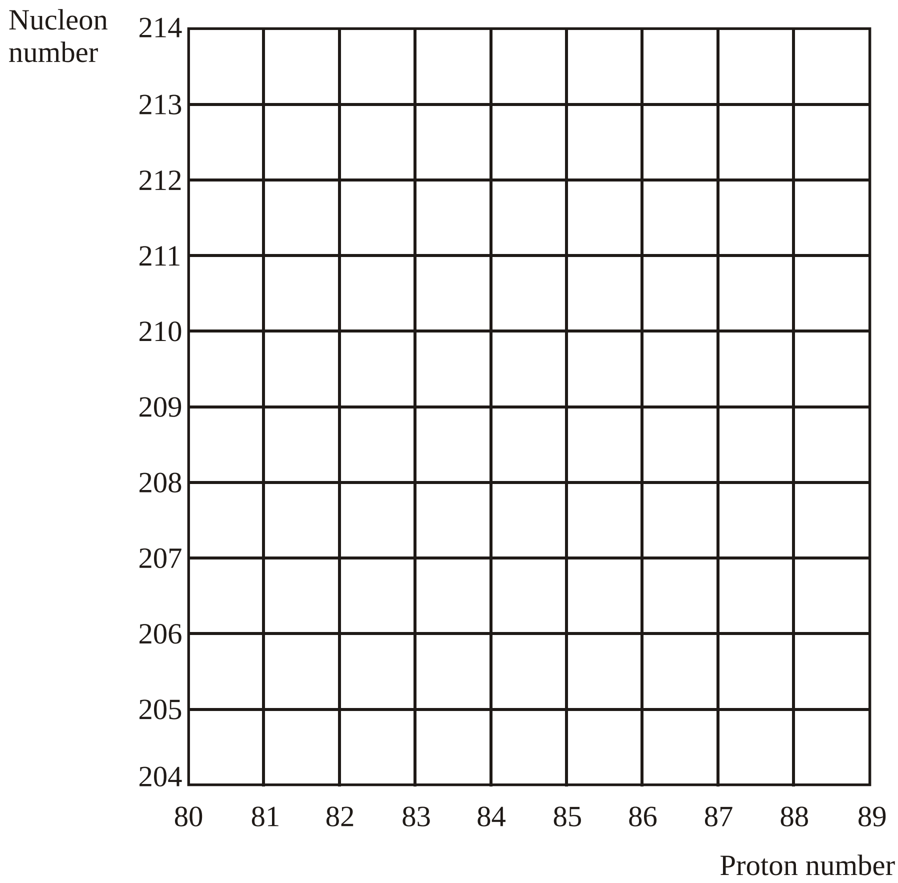
(1)

A nucleus of an isotope of polonium (symbol Po) has 84 protons and 126 neutrons. Mark the position of this nucleus on the grid below, and label it Po.



This isotope of polonium decays by alpha particle emission into an element X. Starting from Po, add a line to the grid to represent this decay.

(3)

This isotope of polonium is thought to emit **only** alpha radiation. Describe how you could check this experimentally.

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(3)
(Total 7 marks)

25. The **range** of nuclear radiation in matter depends on how strongly the radiation **ionises** matter. Explain the meanings of the terms in bold type.

range ....

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ionises ....

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(2)

State and explain the qualitative relationship between range and ionising ability.

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(2)

Beta radiation from a certain source can be stopped completely by a sheet of aluminium 3.0 mm thick. Calculate the mass of a square sheet of aluminium of this thickness measuring 1.0 m × 1.0 m.

(Density of aluminium = 2.7×10^3 kg m^{-3})

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Mass = ...

(2)

To a fair approximation, the ability of any sheet of material to stop beta radiation depends only on the mass per square metre of a sheet of the material. Estimate the thickness of lead sheet needed to stop the same beta radiation completely.

(Density of lead = 11.3×10^3 kg m^{-3})

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Thickness = ...

(2)
(Total 8 marks)

26. Part of the uranium decay series is shown below.

$${}^{238}_{92}\text{U} \rightarrow {}^{234}_{90}\text{Th} \rightarrow {}^{234}_{91}\text{Pa} \rightarrow {}^{234}_{92}\text{U} \rightarrow {}^{230}_{90}\text{Th} \rightarrow {}^{226}_{88}\text{Ra}$$

Write above each arrow the charged particle emitted during that decay.

(2)

The stable end product of the complete uranium decay series is lead, $^{206}_{82}\text{Pb}$. How many alpha particles are emitted between $^{226}_{88}\text{Ra}$ and the end of the series?

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(1)
(Total 3 marks)

27. What do we call the nuclear radiation which is around us all the time?

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(1)

Name one source of this radiation.

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(1)

Suggest why our exposure to radiation is greater today than it was 100 years ago.

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(1)

In factories that produce fabric from synthetic fibres, there may be problems due to the build-up of static charge on the fabric. Beta radiation can be used to reduce the problem.

(i) Give two reasons why beta radiation is chosen rather than gamma radiation.

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(ii) Why is beta radiation chosen rather than alpha radiation?

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(3)

Gamma radiation is used for detecting flaws in an aircraft wing. Why is gamma radiation suitable in this application?

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(2)
(Total 8 marks)

28. The Huygens/Cassini space mission to Titan, a moon of Saturn, left the Earth amid a storm of protest. The protest was about its nuclear-powered battery which contained plutonium-238, an alpha emitter. Before launch in 1997, a newspaper article read

> **PLUTONIUM PROBE PERIL**
>
> NASA is going to send up a space probe with 70 pounds of deadly plutonium on board. The probe is going to be launched using a Titan IV rocket – the same type of rocket that blew up over the Pacific Ocean just 4 years ago in 1993.
>
> Plutonium is so deadly that just one pound of it, spread through the Earth's atmosphere, could cause lung cancer in every person on Earth! Less than one millionth of a gram of it is a deadly dose.

In plutonium-238, what does 238 mean?

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(1)

Why did the plutonium source cause concern?

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(1)

The half-life of plutonium-238 is 88 years and, at launch, the source contained 7.2×10^{25} atoms. Show that the activity of the plutonium source, at the time of launch, was about 2×10^{16} Bq.

(1 year = 3.16×10^{7} s)

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(3)

Each plutonium nucleus releases 5.6 MeV when it decays. Calculate the power (in watts) delivered by the plutonium at the time of the rocket launch.

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Power = ...

(3)

The textbooks say that nuclear decay is a random process. Explain whether this means that there is some doubt that the power can be relied upon.

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(1)

What percentage of the power at launch will still be available 10 years after the launch?

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Percentage = ...

(2)

Suggest why plutonium was chosen for this mission.

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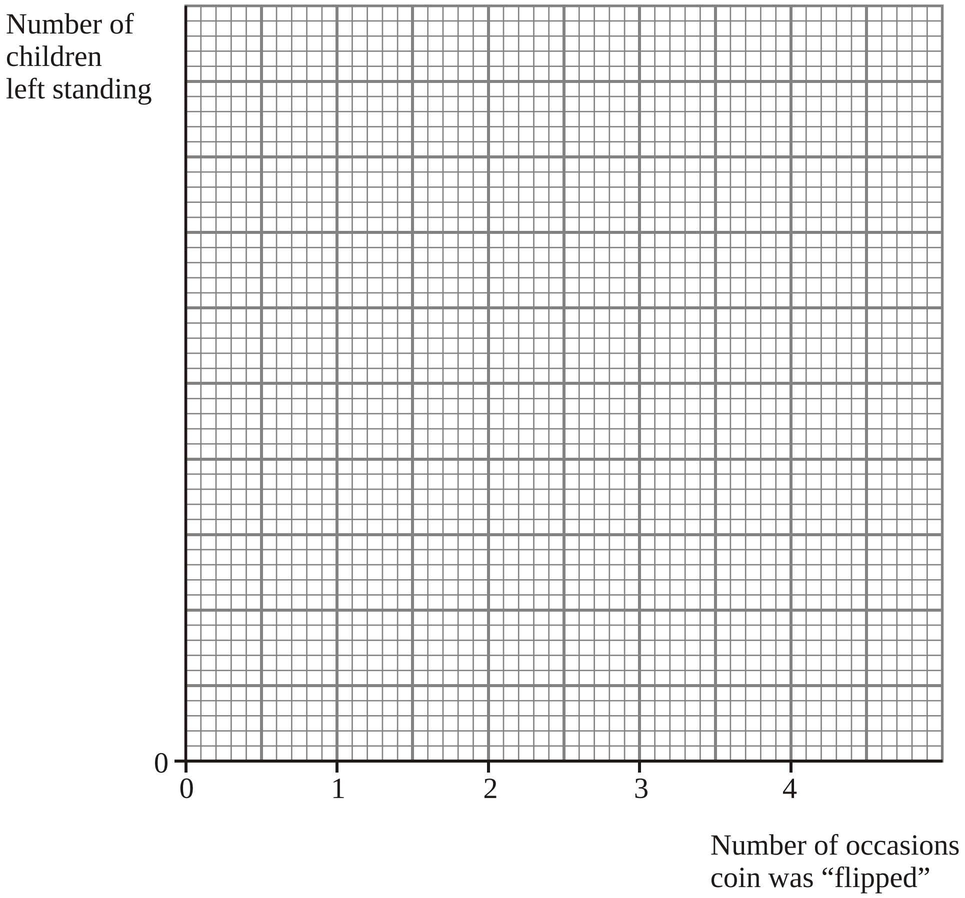
(1)
(Total 12 marks)

29. A physics student asked a large group of children to stand up and perform a simple experiment to model radioactive decay. Each child flipped a coin. Those who flipped a "head" sat down.

The children left standing again flipped a coin and those who flipped a "head" sat down. This process was repeated twice more.

There were initially 192 children standing. Plot on the axes below the expected graph of the results. Add a scale to the *y*-axis.



(3)

Radioactive decay is a **random** process. Explain what this means.

....

....

(1)

In what way is the experiment a model of a random process?

....

....

(1)

What is meant by the **half-life** of a radioisotope?

....

....

(1)

Does the model illustrate half-life? Justify your answer.

....

....

(1)
(Total 7 marks)

30. A student has been writing some revision notes. The dotted lines show where she has left out information. Complete each section for her.

Radiation
Background radiation – is all around us – is ionising – comes from a variety of sources, e.g ....

(1)

Nuclear radiation properties			
	Alpha	Beta	Gamma
Ionising ability	....	Medium	....
Penetrating power (stopped by)	....	....	Many cm lead or m of concrete

(3)
(Total 4 marks)

31. Below are some examples of oscillations. For each, state with a reason whether the motion is simple harmonic or not.

Oscillation	SHM ✓ or ✗	Reason
Mass on end of a spring	....	....
Child jumping up and down	....	....
Vibrating guitar string	....	....

(Total 4 marks)

32. Indium-115 (symbol In, proton number 49) decays by beta-minus emission to tin (symbol Sn). Write down a nuclear equation representing this decay.

....

(2)

Indium-115 has a half-life of 4.4×10^{14} years. Calculate its decay constant.

....

....

....

Decay constant = ...

(2)

A radioactive source contains 2.3×10^{21} nuclei of indium-115. Calculate the activity of this source in becquerels.

....

....

....

....

Activity = ... Bq

State how this activity compares with a normal background count rate.

....

(3)
(Total 7 marks)

33. A Physics department has an old radium source which is thought to emit alpha, beta and gamma radiation. A student performs some experimental tests to find out whether this is correct. She uses a metre rule, a I mm thick sheet of aluminium, a 5 mm thick sheet of aluminium and a suitable Geiger-Müller tube with a ratemeter. Her results are as follows:

Test number	Procedure	Observations on ratemeter
1	The source is held very close to the GM tube.	Count rate is high.
2	The source is moved a few centimetres away from the GM tube.	Count rate suddenly drops.
3	With the source 20 cm from the GM tube, 1 mm of aluminium is inserted between them.	Count rate drops significantly.
4	With source still 20 cm from the GM tube, 5 mm of aluminium is inserted between them.	Count rate is still well above background.

Which test(s) lead to the conclusion that each of alpha, beta and gamma radiation is emitted by the source? Justify your answers.

Alpha:

....

....

Beta:

....

....

Gamma:

....

....

(Total 4 marks)

34. A radioactive isotope of carbon, $^{14}_{6}C$, is continuously produced in the upper atmosphere when neutrons ejected from nuclei by cosmic rays collide with atmospheric nitrogen $^{14}_{7}N$.

Complete the nuclear equation below to show the production of radioactive carbon in the upper atmosphere. Hence identify X, the other product of the reaction.

$$^{\cdots\cdots}_{\cdots\cdots}N + \,^{\cdots\cdots}_{\cdots\cdots}n \rightarrow \,^{14}_{6}C + \,^{\cdots\cdots}_{\cdots\cdots}X$$

X = ...

(3)

Living plants take up carbon dioxide from the atmosphere and have a normal activity of 15.3 counts per minute per gram of carbon due to absorption of some carbon dioxide containing carbon-14. On death, the plant no longer takes in carbon-14 and the amount already taken up decays with a half-life of 5730 years.

Estimate the age of an archaeological specimen with an activity of 1.9 counts per minute per gram of carbon.

....

....

....

(3)

Suggest one problem in measuring an activity as low as 1.9 counts per minute per gram of carbon.

....

....

(1)
(Total 7 marks)

35. How many neutrons does the nucleus of $^{14}_{6}C$ contain?

....

Carbon-14 has a half-life of 5600 years. Calculate the decay constant of carbon-14.

....

....

Decay constant = ...

(3)

A sample of 14g of carbon-14 contains 6.0×10^{23} nuclei.

How many nuclei are there in 7.0×10^{-9} g of carbon-14?

....

....

Number of nuclei = ...

Hence calculate the activity of 7.0×10^{-9} g of carbon-14.

....

....

....

Activity = ...

(3)

Carbon-14 is a beta-minus emitter and its decay product is a nucleus of nitrogen, N. Write down a nuclear equation demonstrating this decay.

....

(2)
(Total 8 marks)

36. Scientists have worked out the age of the Moon by dating the rocks brought back by the Apollo missions. They use the decay of potassium-40 to stable argon-40 in the rocks; this process has a half life of 1.3×10^9 years. In one rock sample, the scientists found 0.84 μg of argon-40 and 0.10 μg of potassium-40.

Use the data above to calculate the age of the Moon.

(Allow one lined page)

(Total 6 marks)

37. A school physics department has a cobalt-60 gamma ray source. Its half-life is several years. As a project, a student decides to try to measure this half-life. She sets up a GM tube close to the source and determines the count produced by the source in a 10 minute period. One year later she repeats the measurement.

Explain **two** precautions, other than safety precautions, which the student should take in her measurements in order to produce a reliable value for the half-life.

....

....

....

....

....

(3)

The student then calculates the count she would expect to get in a 10 minute period if she repeated her measurement annually. Some of her results are shown in the table below.

Time/year	**Count in 10 minute period**
0	17 602
1	15 489
2	13 630
3	
4	10 554
5	9287
6	8172
7	7191

Calculate the ratio of the count after one year to the initial count.

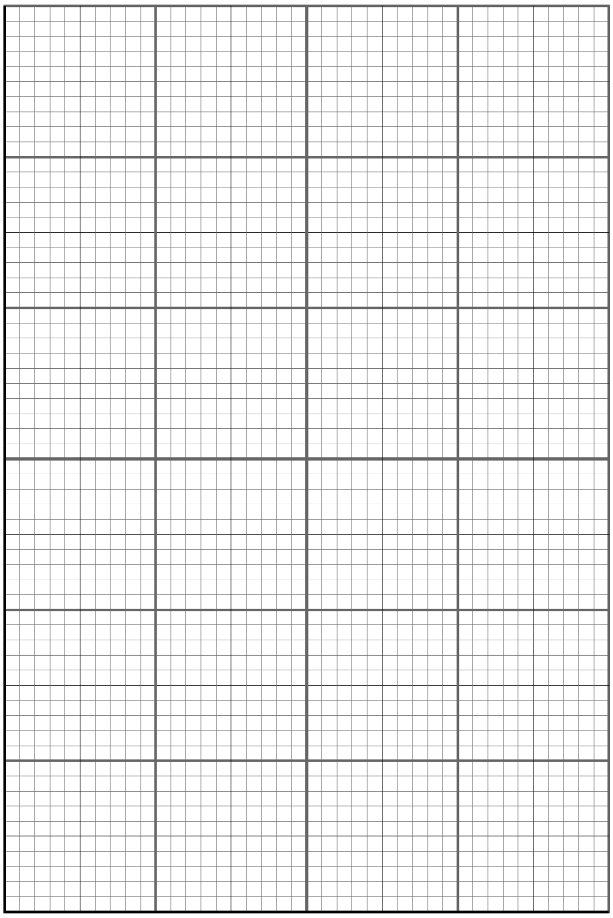
Ratio = ...

(1)

Complete the table to show the count you would expect for year 3.

(1)

On the axes below, plot a graph of count against time.



Use your graph to determine a value for the half-life of cobalt-60.

....

Half-life = ...

(4)
(Total 9 marks)

38. Below are the symbols for some nuclei of the element tin.

$^{111}_{50}\text{Sn}$ $^{112}_{50}\text{Sn}$ $^{113}_{50}\text{Sn}$ $^{114}_{50}\text{Sn}$ $^{115}_{50}\text{Sn}$

What name is given to different nuclei of this type?

....

(1)

$^{111}_{50}$Sn decays by beta-plus emission into indium (In). Write a balanced nuclear equation for this decay.

....

(2)

Which nucleus in the list is likely to produce the densest material?

....

(1)
(Total 4 marks)

39. Young people have swum for many years in an unusually warm Siberian river near to a secret nuclear fuel reprocessing factory. This factory has made regular discharges of nuclear waste into the river.

Why is the river **unusually warm?**

....

....

(1)

Alpha (α), beta (β) and gamma (γ) radiation can be emitted by the radioactive waste. What are each of these?

α ....

....

β ....

....

γ ....

....

(3)

For the swimmers' health, which are the most hazardous radioactive nuclei in the water: those emitting α, β or γ radiation?

....

Explain your answer.

....

....

....

....

(2)

Some people say that the water would still be radioactive if the factory were not there, since we live in a radioactive world. Where could this radioactivity come from?

....

....

(1)
(Total 7 marks)

40. Samples of two different isotopes of iron have been prepared. Compare the compositions of their nuclei.

....

....

The samples have the same chemical properties. Suggest a physical property which would differ between them.

....

(3)

Tritium (hydrogen-3) is an emitter of beta particles. Complete the nuclear equation for this decay.

$$\text{H} \rightarrow \qquad \text{He} \quad + \qquad \beta$$

(3)

Describe how you would verify experimentally that tritium emits only beta particles.

....

....

....

....

....

....

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....

....

(4)
(Total 10 marks)

41. A radioactive source contains barium-140. The initial activity of the source is 6.4×10^8 Bq. Its decay constant is 0.053 day^{-1}.

Calculate the half-life in days of barium-140.

....

....

....

Half-life = ... days

Calculate the initial number of barium-140 nuclei present in the source.

....

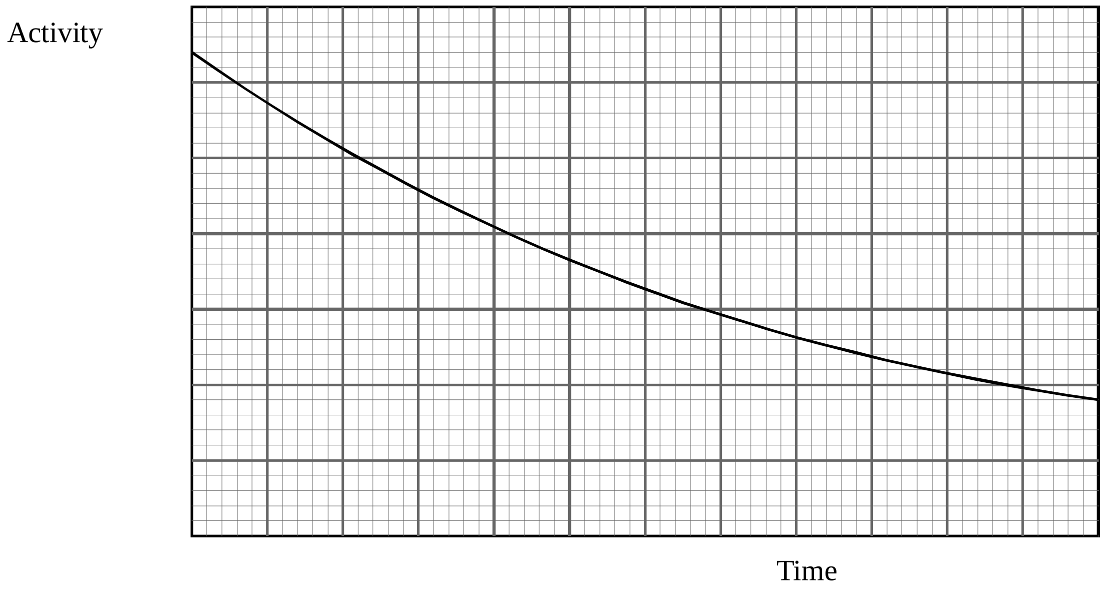
....

....

Number of nuclei = ...

(4)

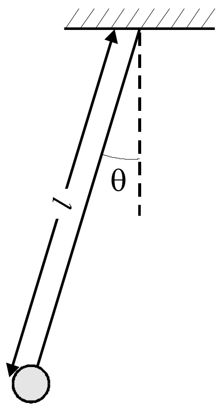
The graph below represents radioactive decay. Add a suitable scale to each axis, so that the graph correctly represents the decay of this barium source.



A radium-226 source has the same initial activity as the barium-140 source. Its half-life is 1600 years. On the same axes sketch a graph to show how the activity of the radium source would vary over the same period.

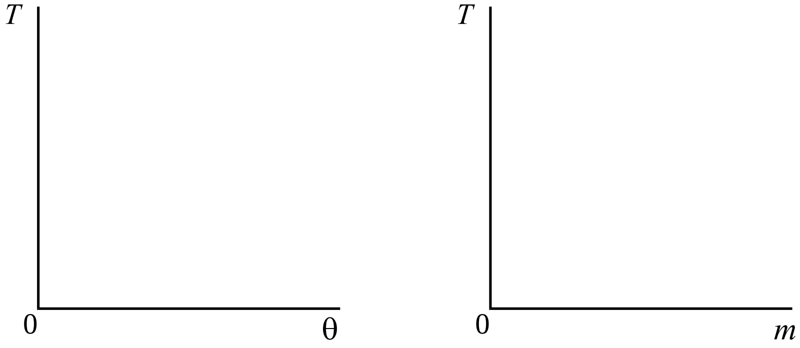
(3)
(Total 7 marks)

42. A simple pendulum of length l has a bob of mass m.



A student studies the variation of its time period T with the angle θ (which is a measure of the amplitude of the motion), the mass m and the length l.

On the axes below show how T varies with θ and with m.



(2)

Describe how the student could verify experimentally that $T \propto \sqrt{l}$.

....

....

....

....

....

....

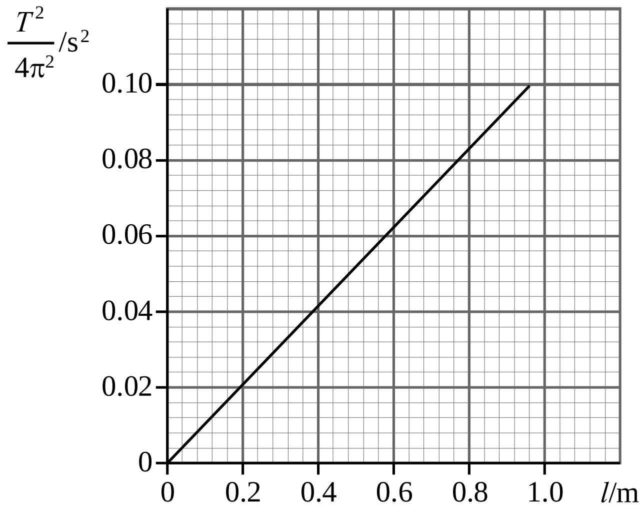
....

....

....

(4)

Below is a graph of $\frac{T^2}{4\pi^2}$ against l.



Calculate the rate of change of $\frac{T^2}{4\pi^2}$ with l.

....

....

Rate of change = ...

Find the rate of change of l with $\frac{T^2}{4\pi^2}$ and comment on your answer.

....

....

....

....

(4)
(Total 10 marks)

43. Phosphorus $^{32}_{15}P$ is unstable and decays by β^- emission to sulphur, S. Write a nuclear equation for this decay.

....

(1)

Describe how, using a Geiger counter and suitable absorbers, you could show that an unstable nuclide of long half-life emitted *only* β^- radiation.

....

....

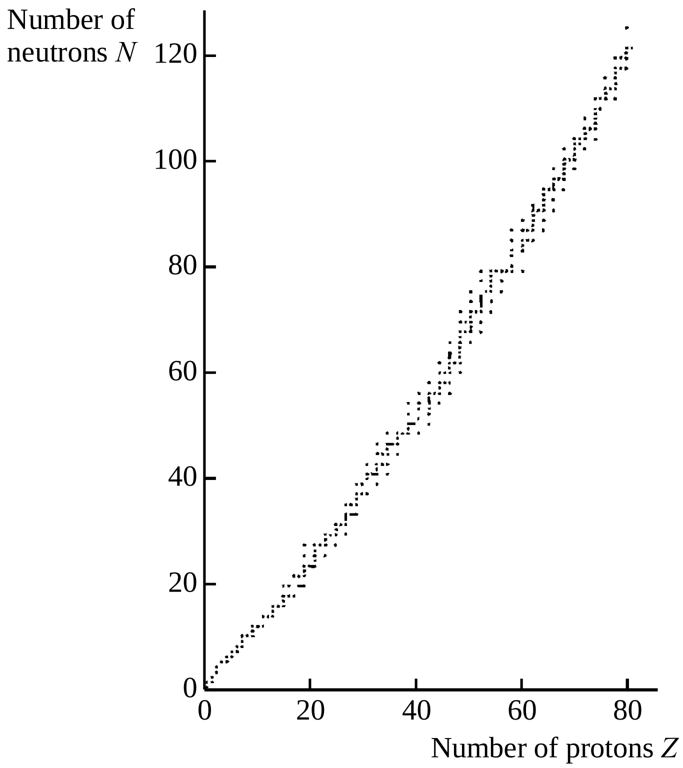
....

....

....

(4)

The scatter diagram shows the relationship between the number of neutrons and the number of protons for stable nuclides.



Show on the diagram the region where nuclides which decay by β^- emission would be found.

Use the diagram to help you explain your answer.

....

....

....

....

....

(3)
(Total 9 marks)

44. A student measured the background radiation in a laboratory at 4.0 Bq. State **two** sources of background radiation.

....

....

(2)

Sodium-22 decays by beta-plus radiation to neon.

Complete the nuclear equation ensuring that each symbol has the appropriate nucleon and proton number.

$$^{22}_{11}\text{Na} \rightarrow \quad \text{Ne} \quad +$$

Write down another possible isotope of sodium.

Na

(3)

Sodium-22 has a half-life of 2.6 years.

Determine the decay constant of sodium-22 in s^{-1}.

....

....

Decay constant = ...s^{-1}.

A sample of common salt (sodium chloride) is contaminated with sodium-22. The activity of a spoonful is found to be 2.5 Bq. How many nuclei of sodium-22 does the spoonful contain?

....

....

Number of nuclei = ...

(4)

Explain whether your answer suggests that the salt is **heavily** contaminated.

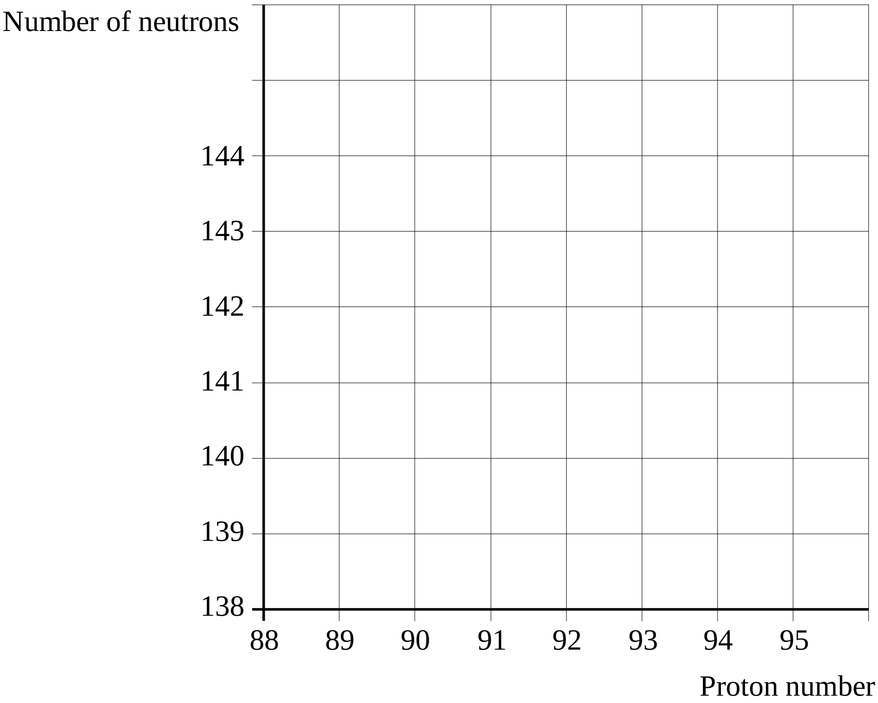
....

....

....

(1)
(Total 10 marks)

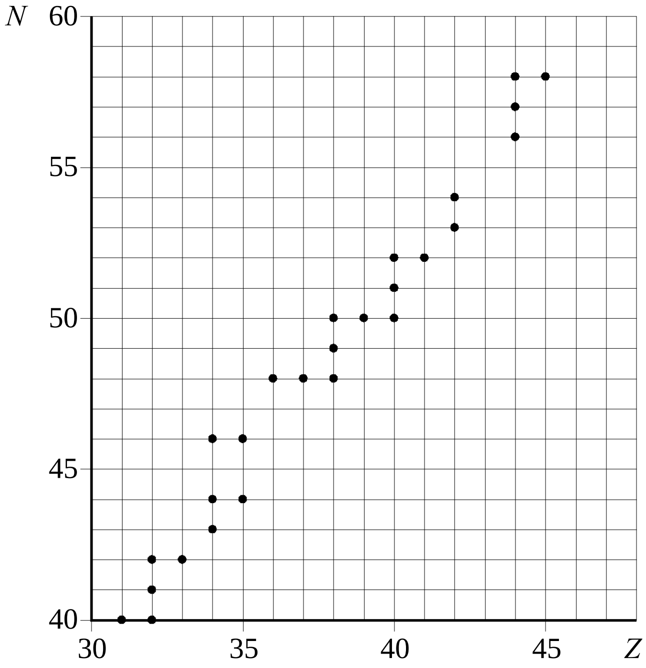
45. Protactinium, Pa, decays to uranium $^{234}_{92}U$ by emitting a beta-minus particle. The uranium produced is itself radioactive and decays by alpha emission to thorium, Th.



Mark and label the position of $^{234}_{92}U$. Draw lines on the grid showing both the beta-minus and the alpha decays. Label your lines α and β.

(Total 4 marks)

46. The grid shows the relationship between number of neutrons *N* and number of protons *Z* for some of the **stable** nuclides in the region *Z* = 31 to Z = *45*.



Strontium-90, ${}^{90}_{38}Sr$, is an unstable nuclide. It decays by β^- emission to an unstable isotope of yttrium. On the graph mark the position of ${}^{90}_{38}Sr$ and this isotope of yttrium.

(2)

${}^{82}_{37}Rb$ is another unstable nuclide. Mark the position of ${}^{82}_{37}Rb$ on the graph.

By what means would you expect ${}^{82}_{37}Rb$ to decay?

....

(2)
(Total 4 marks)

47. A student has a sample of a radioactive element which is thought to be a pure beta emitter. The student has **only** the following apparatus available:

- a thin window Geiger-Muller tube connected to a counter
- a piece of aluminium 3 mm thick, and
- a half-metre rule

How would the student determine the background radiation level in the laboratory?

....

....

....

....

(2)

The student investigates how the count rate varies with distance from the source to the G-M tube and also the effect of inserting the aluminium absorber. From these experiments explain how the student could confirm that the sample was a pure beta emitter. You may be awarded a mark for the clarity of your answer.

....

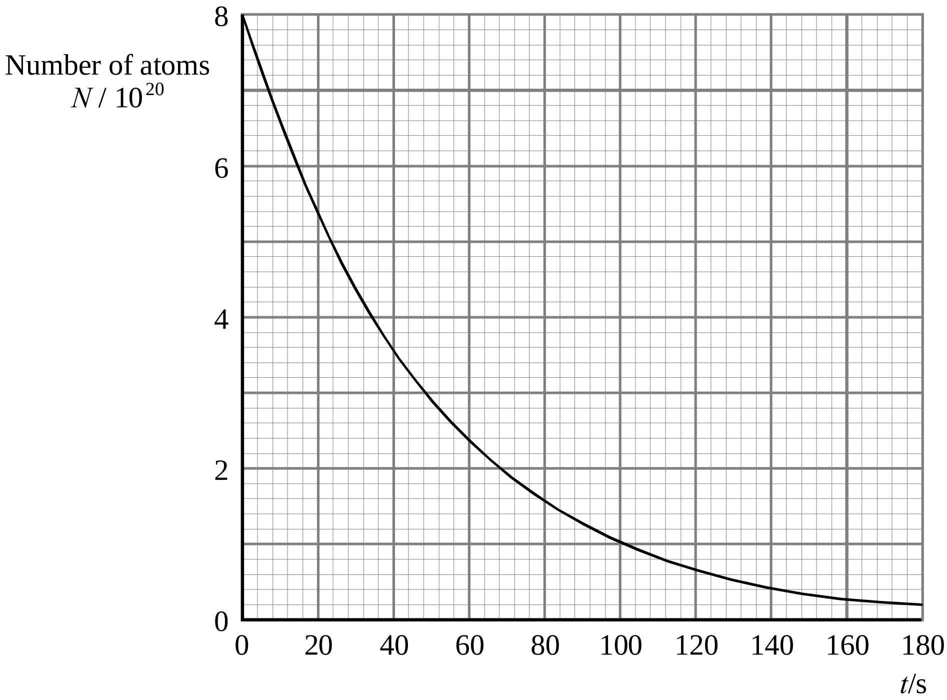
....

....

....

(5)
(Total 7 marks)

48. The graph shows the decay of a radioactive nuclide.



Determine the half-life of this radionuclide.

....

....

....

Half-life = ...

(2)

Use your value of half-life to calculate the decay constant λ of this radionuclide.

....

....

Decay constant = ...

(1)

Use the graph to determine the rate of decay dN/dt when $N = 3.0 \times 10^{20}$.

....

....

....

....

Rate of decay = ...

(3)

Use your value of the rate of decay to calculate the decay constant λ of this radionuclide.

....

....

....

Decay constant = ...

(2)

Explain which method of determining the decay constant you consider to be more reliable.

....

....

(1)
(Total 9 marks)

49. A mass is suspended from a spring. The mass is then displaced and allowed to oscillate vertically. The amplitude of the oscillations is 6.0mm. The period of the oscillations is 3.2s.

Calculate the maximum acceleration of the mass.

....

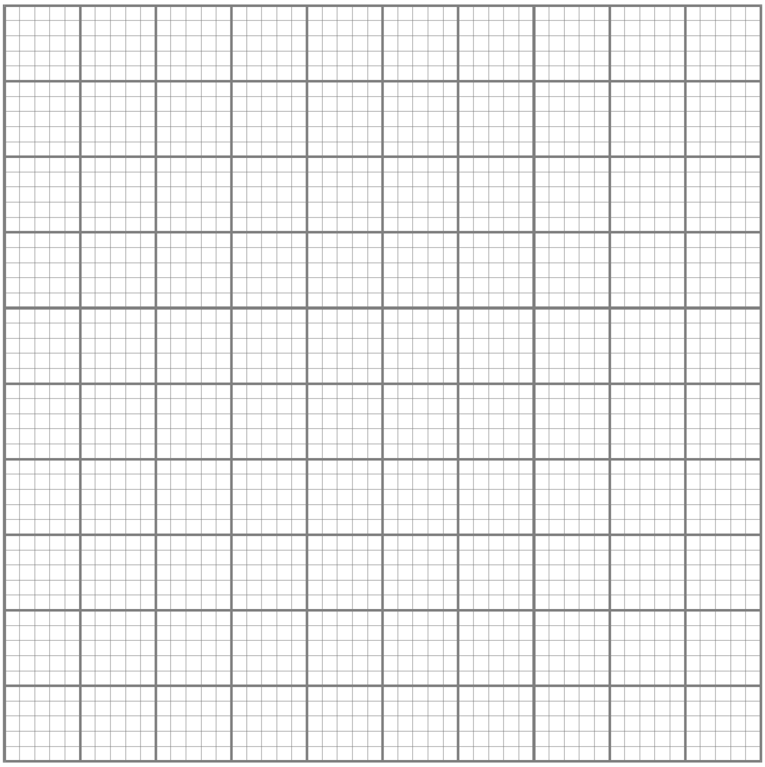
....

....

Maximum acceleration = ...

(3)

Sketch a graph showing how the acceleration of the mass varies with displacement. Add a scale to both axes.



(4)

State and explain *one* reason why the mass may not oscillate with simple harmonic motion.

....

....

....

(2)
(Total 9 marks)

50. (i) Radioactivity is a random process. Explain what is meant by this statement.

(ii) The decay of a sample of radioactive material can be described by the equation.

$$\frac{dN}{dt} = -\lambda N$$

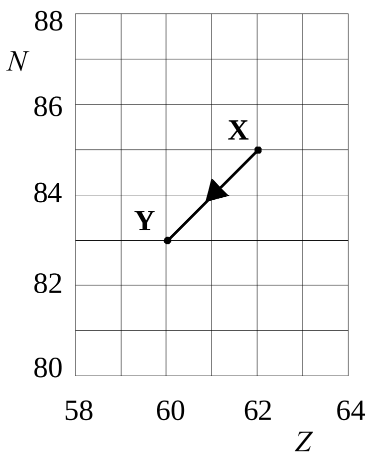
where d*N*/dt is the activity of the sample.

Calculate the activity of a sample of nitrogen–13 when N=2.5 × 10^5. The half-life of nitrogen–13 is 10 minutes.

(iii) Nitrogen–13 ($^{13}_{7}$N) decays to a stable nuclide by emitting a beta-plus particle. Write an equation for this process.

(Total 7 marks)

51. The grid enables different nuclei to be represented by plotting the number of neutrons *N* against the number of protons *Z* in a nucleus. The arrow shows a nucleus X decaying to a nucleus Y.



What type of radioactive decay is taking place?

....

Write a nuclear equation for this decay.

....

Add another arrow to the grid to represent what happens if nucleus Y subsequently decays by β^- emission to nucleus W.

Mark a point P on the grid that could represent the nucleus of an isotope of X.

(Total 5 marks)

52. It is thought that some soil could be contaminated with a radioisotope.

You have a sample of this soil. Design an experiment to find what types of radiation are emitted.

....

....

....

....

....

....

....

....

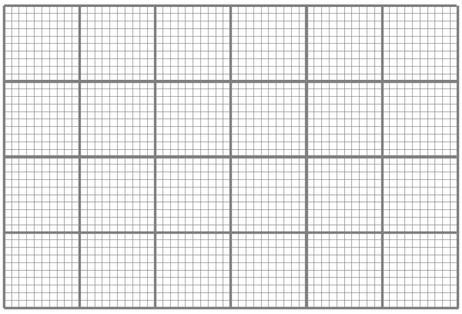
....

....

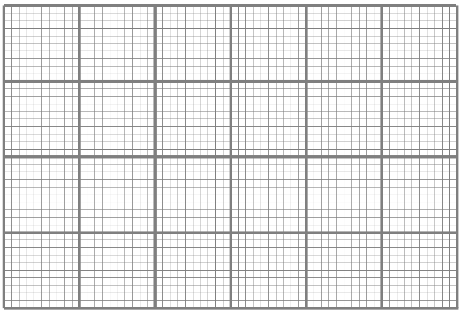
(Total 5 marks)

53. A mass moves with simple harmonic motion. The displacement x of the mass varies with time t according to the relationship $x = x_0 \sin 2\pi ft$.

On the grids provided sketch two graphs, one showing the variation of acceleration of this mass with time, the other showing the variation of acceleration with displacement.



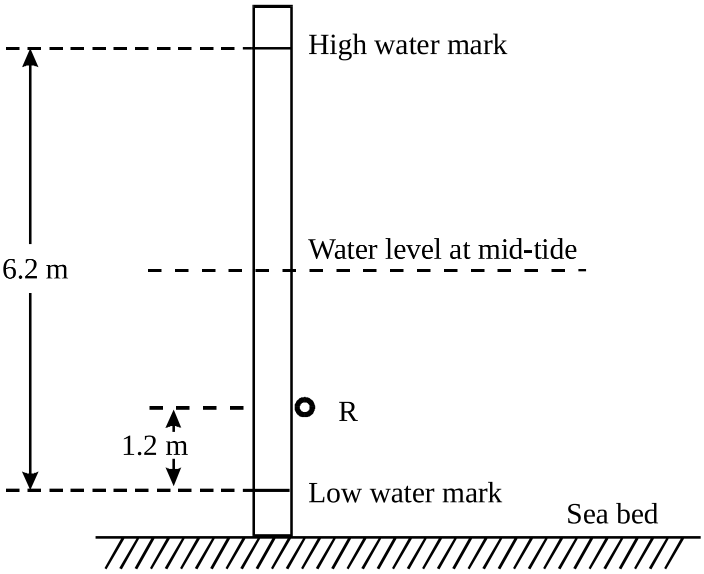
Acceleration – time graph



Acceleration – displacement graph

(4)

The movement of the tides may be assumed to be simple harmonic with a period approximately equal to 12 hours. The diagram shows a vertical wooden pole fixed firmly to the sea bed. A ring is attached to the pole at point R.



What is the amplitude of this tide?

....

High tide on a particular day is at 9 a.m. State the times of the next mid-tide and the next low tide.

Next mid-tide: ……….........……..............………………………………………………..

Next low tide: ……….........……..............………………………………………………..

(3)

Calculate the time at which the falling water level reaches the ring R.

....

....

....

....

....

....

....

....

....

....

Time =……….........……...............

(4)

(Total 11 marks)