Section 4: Atomic Structure 1

1.1	Where is almost all of the **mass** of the atom?	In the **nucleus**
1.2	How does the **radius** of the nucleus compare to the radius of the atom?	The nucleus is approximately 10,000 smaller than the atom Atom**: 10^{-10} m** Nucleus: **10^{-15} m**
1.3	**What is the nucleus of the atom composed of?**	**Positively charged protons and neutral neutrons**
1.4	What **surrounds** the nucleus of an atom?	Negatively charged electrons
1.5	What do all nuclei of atoms of the **same element** have in common?	Number of protons
1.5	How can you calculate the number of neutrons in an atom?	Mass number – atomic number
1.6	What is the definition of an **isotope**?	Atoms of the **same element** having the **same number of protons** with a **different number of neutrons**
1.7	**What was the plum-pudding model of the atom?**	**An early model of the atom where the atom was a ball of positive charge with negative electrons embedded throughout.**
1.8	**What was the nuclear model of the atom?**	**The model that was proposed after the plum-pudding model, with atoms have a <u>small</u> positively charged nucleus surrounded by negative electrons**
1.9	How are **electrons arranged** around the atomic nucleus?	Orbit at fixed distances in shells/energy levels.
1.10	What happens to an atom's electrons when **electromagnetic radiation** is **absorbed** or **emitted**?	Electrons move between energy levels. (Excited up energy levels – absorb EM) (Relax down energy levels – release EM)
1.11	**What was observed by Rutherford's scattering experiment?**	**1) most of the alpha particles did pass straight through the foil** **2) small number of alpha particles were deflected by large angles as they passed through the foil** **3) a <u>very small</u> number of alpha particles bounced back straight back off the foil**
1.12	What are the **conclusions** about the structure of the atom made by the Rutherford scattering experiment?	1) most of the atom is empty space 2) there is a concentration of positive charge in the atom 3) the positively charged nucleus is **<u>very small</u>** (the nucleus)
1.13	Who claimed elements are made from atoms which are **indivisible**?	Dalton
1.14	Who discovered the **electron**?	Thompson
1.15	Who discovered the **nucleus**?	Rutherford
1.16	Who proposed the idea of electrons orbiting the nucleus at specific distances (in **shells)**?	Bohr
1.17	Who discovered the **neutron**?	Chadwick
1.18	Why might **scientific theories/models** be changed?	When new evidence is discovered that cannot be explained with the current model

Section 4: Atomic Structure 2

2.1	What is **ionisation**?	An atom is turned into an ion (charged particle) by the loss or gain of an electron
2.3	What is the **relative mass** and **relative charge** of a **proton**?	Relative mass: 1 Relative charge: +1
2.4	What is the **relative mass** and **relative charge** of an **electron**?	Relative mass: ≈ 0 Relative charge: -1
2.5	What is the **relative mass** and **relative charge** of a **neutron**?	Relative mass: 1 Relative charge: 0
2.6	Name the 4 ways an **unstable** nucleus may become more stable	By emitting an alpha particle, beta particle, or gamma radiation, or a neutron
2.7	**What is an alpha particle made of?**	**2 protons and 2 neutrons** **(helium nucleus)**
2.8	**What is the relative mass of an alpha particle**	**4**
2.9	**What is the relative charge of an alpha particle?**	**+2**
2.10	**What are the two symbols for alpha particles?**	${}^{4}_{2}He \qquad {}^{4}_{2}\alpha$
2.11	**What is a beta particle made of?**	**A fast-moving electron**
2.12	**What is the relative mass of a beta particle?**	**0**
2.13	**What is the relative charge of a beta particle?**	**-1**
2.14	**What are the two symbols for beta particles?**	${}^{0}_{-1}e \qquad {}^{0}_{-1}\beta$
2.15	**What is gamma radiation?**	**High energy electromagnetic wave emitted from an unstable nucleus**
2.16	How is the **nucleus** affected by the emission of an **alpha** particle?	Nucleus loses 2 protons and 2 neutrons so mass decreases **by 4**, atomic (proton) number decreases **by 2**
2.17	How is the **nucleus** affected by the emission of a **beta** particle	A neutron turns into a proton and an electron (which is emitted)… so mass stays the same, **atomic (proton) number increases by 1**
2.18	How is the **nucleus** affected by the emission of a **gamma** wave?	There is no change to mass number or atomic number

Section 4: Atomic Structure 3

3.1	What is meant by the **activity** of a radioactive sample?	The number of decays per second (measured in Becquerel's)
3.2	How is radiation **detected**?	Geiger-Muller tube
3.3	What are the 2 definitions of **half-life**?	The average time taken for the number of radioactive nuclei to halve The average time taken for the activity to reduce by half
3.4	**What is meant by the 'random' nature of radioactive decay?**	**Cannot predict which nucleus will decay or when.**
3.5	How do the **penetration** properties of alpha-particles, beta-particles and gamma waves compare?	Alpha the least penetrating (stopped by paper/skin) Beta in the middle (stopped by few mm of aluminium) Gamma waves are the most penetrating (only stopped by a few cm of lead or a few metres of concrete)
3.6	Compare the **range** in air of alpha, beta and gamma radiation	Alpha – few cm Beta – approx. metre Gamma – Technically infinite range but decreases significantly so not usually detectable from a source after approx. 10m
3.7	Compare the **ionising ability** of alpha, beta, and gamma radiation	Least -> Most Gamma: Mildly ionising Beta: Moderately ionising (due to -1 charge) Alpha: Highly ionising (due to +2 charge)
3.8	Why is **ionising radiation** dangerous?	If radiation **ionises** atoms that make up DNA, may causes **DNA damage** (and cell death) or **mutations** which increases risk of **tumours** developing
3.9	What is the difference between **contamination** and **irradiation**?	In **contamination**, a radioactive material is transferred to the object in question (is actually on it). In **irradiation**, no radioactive material is transferred: the object experiences radiation from a source separate from it (doesn't "stick" to it).
3.10	**How can you protect from contamination?**	**Wear gloves / apron / do not touch source with bear hands**
3.11	**How can you protect from irradiation?**	**Increase distance from source / decrease time exposed / use lead lined shield/clothing**
3.12	What happens to the **activity** of a radioactive source over time?	It reduces according to its half-life but never get to zero
3.13	How does the **half-life** affect the **risk** from a radioactive source?	The shorter the half-life, the faster the risk will decrease

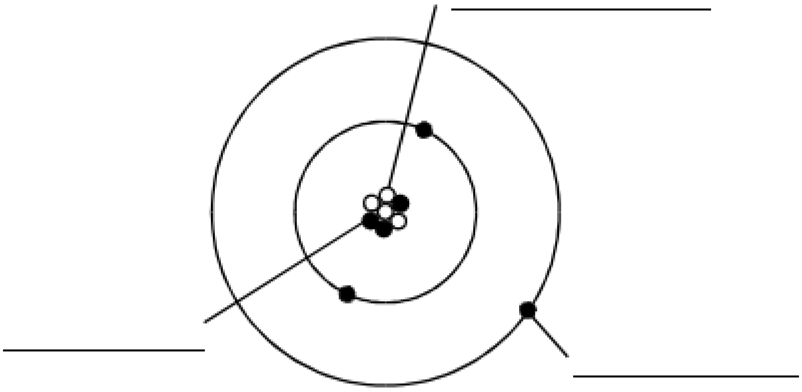
Section 5: Atomic Structure (Triple Content)

5.1	How does a **radioactive tracer** in medicine work?	The patient is injected with a solution containing a **gamma** source, which is then absorbed by the organ. A radiation detector is placed next to the patient and receives the emitted gamma rays outside the body, which are used to build up an image of the organ.
5.2	How is **gamma radiation** used to treat **cancer**?	In **radiotherapy,** a narrow beam of gamma rays is directed at a tumour to destroy cancerous cells, by **ionisiation**.
5.3	How are **radioactive implants** used to treat cancer?	A permanent implant containing a gamma or beta source is placed inside the patient's body and irradiates cancer cells
5.4	What is **background radiation**?	Radiation we are exposed to everyday by the environment
5.5	Name **man-made** sources of **background radiation.**	Nuclear reactors/waste Nuclear accidents and nuclear weapons testing
5.6	Name **natural** sources of **background radiation**	Food/drink Rocks/building materials Cosmic rays Radon gas
5.7	**What happens in nuclear fission?**	**A uranium nucleus absorbs a neutron and splits into two smaller nuclei and two or three neutrons. Energy is released in the form of gamma waves.**
5.8	How does a nuclear fission **chain reaction** occur?	Neutrons released from fission are absorbed by other nuclei, which become unstable and split. The process repeats.
5.9	What is the role of the **control rods** in a nuclear reactor?	Rods made of **boron** control the rate of the chain reaction by absorbing neutrons. Lowering the rods decreases the rate of the chain reaction as more neutrons are absorbed.
5.10	What is the role of the **moderator** in a nuclear reactor?	To reduce the speed of neutrons so they are more likely to be absorbed by a uranium nucleus
5.11	**What happens in nuclear fusion?**	**Two small nuclei fuse together to form a single larger nucleus. Some of the mass is converted into energy, which is emitted as gamma rays.**
5.12	What happens to the missing mass in nuclear fusion?	It is converted to energy
5.13	What radiation is emitted by nuclear fusion?	Gamma radiation

Atomic Structure Foundation/Higher

Q1.

The diagram represents an atom of lithium.



(i) Complete the diagram by writing in the spaces the name of each type of particle. Use only words given in the box. Each word may be used once or not at all.

electron	**neutron**	**nucleus**	**proton**

(3)

(ii) Which type of particle found inside the atom is uncharged?

____

(1)

(iii) What is the mass number of this atom, 3, 4, 7 or 10?

____

Give a reason for your choice.

____

____

(2)

(Total 6 marks)

Q2.

Radioactive nuclei can emit alpha, beta or gamma radiation.

(a) Which type of radiation is the most penetrating?

Tick **one** box.

Alpha (α) ☐

Beta (β) ☐

Gamma (γ) ☐

(1)

(b) Which type of radiation is the most ionising?

Tick **one** box.

Alpha (α) ☐

Beta (β) ☐

Gamma (γ) ☐

(1)

(c) Which type of radiation has the longest range in air?

Tick **one** box.

Alpha (α) ☐

Beta (β) ☐

Gamma (γ) ☐

(1)

When radioactive isotopes in the Earth's crust decay they release energy.

The decay causes the heating of rocks in the crust.

(d) The diagram below shows the decay of uranium-238 (U-238) into thorium-234 (Th-234).

$$^{238}_{92}U \rightarrow ^{234}_{90}Th + ^{4}_{2}He$$

Complete the table below to show the number of neutrons and protons in the nuclei.

Isotope	**Number of neutrons**	**Number of protons**
uranium-238	146	
thorium-234		90

(2)

(e) Geothermal power stations pump water through heated rocks.

The temperature of the water increases from 20 °C to its boiling point of 100 °C

Calculate the change in thermal energy when the mass of water heated is 150 kg

Specific heat capacity = 4 200 J/kg °C

Use the Physics Equations Sheet.

____

____

____

Change in thermal energy = ____________________ J

(3)

(Total 8 marks)

Q3.

Protactinium (Pa) is radioactive.

(a) An atom of one isotope of protactinium contains 91 protons and 143 neutrons.

What is the correct symbol for this atom?

Tick (✓) **one** box.

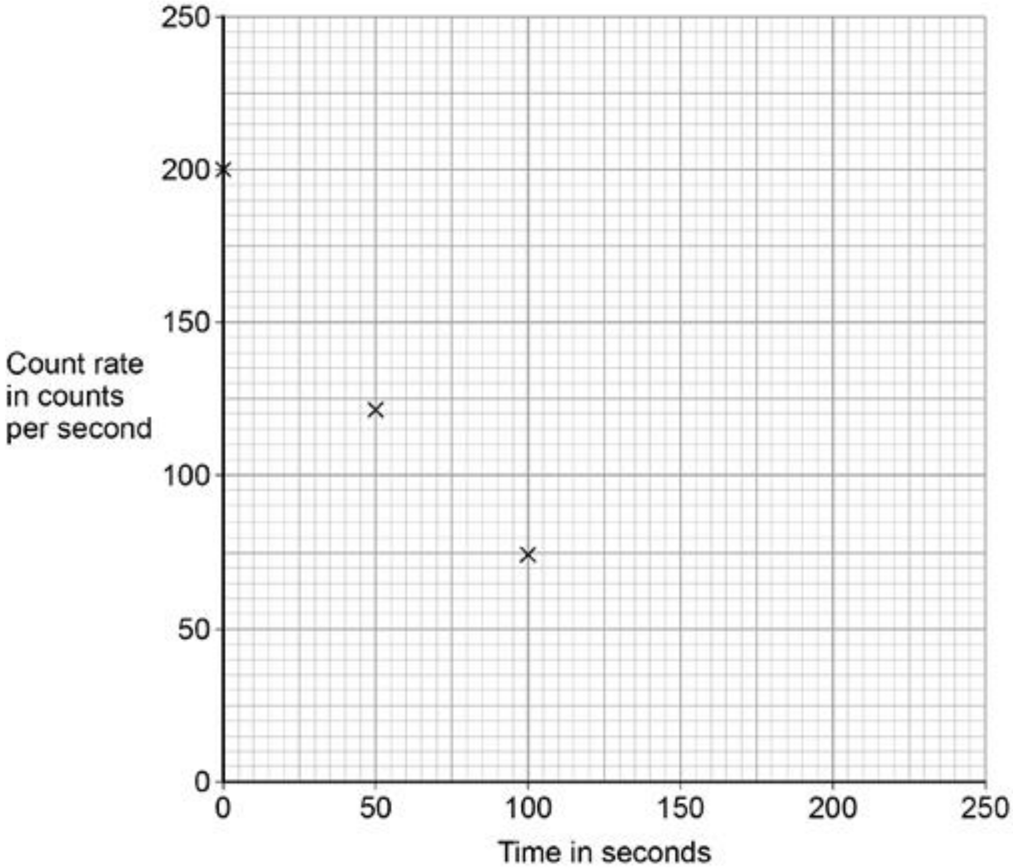
$^{143}_{91}Pa$ ☐ $^{234}_{91}Pa$ ☐ $^{234}_{143}Pa$ ☐ $^{91}_{52}Pa$ ☐

(1)

A teacher investigated how the count rate from a sample of protactinium changed over time.
The table shows the results.

Time in seconds	Count rate in counts per second
0	200
50	122
100	74
150	45
200	27

The graph below shows some of the teacher's results.



(b) Complete the graph.

Use data from the table above.

Draw the line of best fit.

(2)

(c) How much time did it take for the count rate to change from 200 counts per second to 100 counts per second?

____

Time taken = ______________________ s

(1)

(d) What is the half-life of protactinium?

Half-life = ____________________ s

(1)

(e) The nuclear radiation from the protactinium can pass through paper.

This radiation can only be detected up to 1 metre away from the protactinium.

What type of radiation is emitted by the protactinium?

Tick (✓) **one** box.

Alpha ☐

Beta ☐

Gamma ☐

Neutron ☐

(1)

(f) The teacher read an article about the effects of radiation on the human body.

Why are articles in scientific journals generally more trustworthy than articles in newspapers?

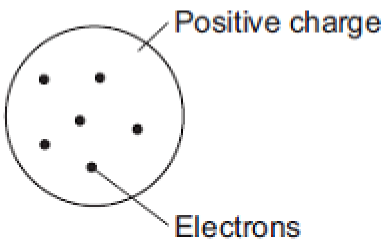
____

____

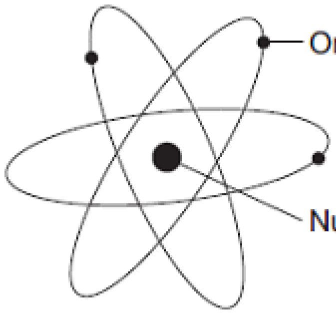
(1)

(Total 7 marks)

Q4. In the early part of the 20th century, scientists used the 'plum pudding' model to explain the structure of the atom.



Following work by Rutherford and Marsden, a new model of the atom, called the 'nuclear' model, was suggested.



Describe the differences between the two models of the atom.

___

___

___

___

___

___

___

___

(Total 4 marks)

Higher

Q5. Lanthanum-140 is a radioactive isotope.

(a) A nucleus of lanthanum-140 emits gamma radiation.

What happens to the mass number and the charge of the nucleus when gamma radiation is emitted?

Tick (✓) **one** box.

Mass number	**Charge**	
Decreases	Decreases	☐
Decreases	Stays the same	☐
Stays the same	Decreases	☐
Stays the same	Stays the same	☐

(1)

(b) Why is it difficult to detect gamma radiation?

____

____

(1)

(c) Activity is the rate at which a radioactive source decays.

A teacher measured the count-rate from a sample of lanthanum-140 using a Geiger-Muller (G-M) tube.

Explain why the count rate was less than the activity of the sample of lanthanum-140

____

____

____

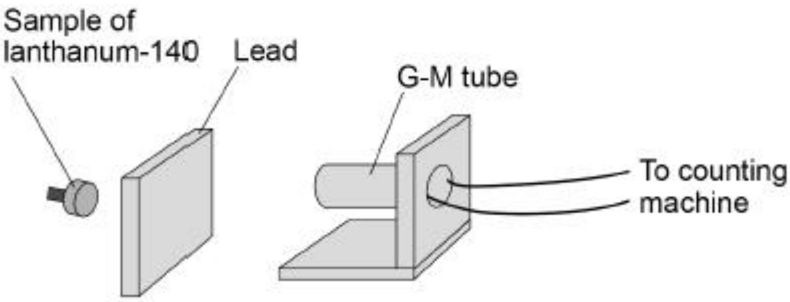
____

(2)

The teacher investigated how the thickness of lead affected the amount of gamma radiation that could pass through it.

Figure 1 shows the apparatus.

Figure 1



(d) Explain why the teacher stood as far away from the apparatus as possible.

____

____

____

____

(2)

The table shows the results.

Thickness of lead in cm	Count rate in counts per second
0.5	110
1.0	60
1.5	33
2.0	18
2.5	10

(e) The teacher concluded that the count rate was **not** inversely proportional to the thickness of lead.

Explain why the teacher was correct.

Use the data in the table above.

____

____

____

____

____

____

(3)

(f) Lanthanum-140 can also emit beta radiation and change into cerium.

Complete the equation showing the decay of lanthanum (La) 140 into cerium (Ce).

$$^{140}_{57}\mathrm{La} \longrightarrow {}^{\_\_}_{\_\_}\mathrm{e} + {}^{\_\_}_{\_\_}\mathrm{Ce}$$

(2)

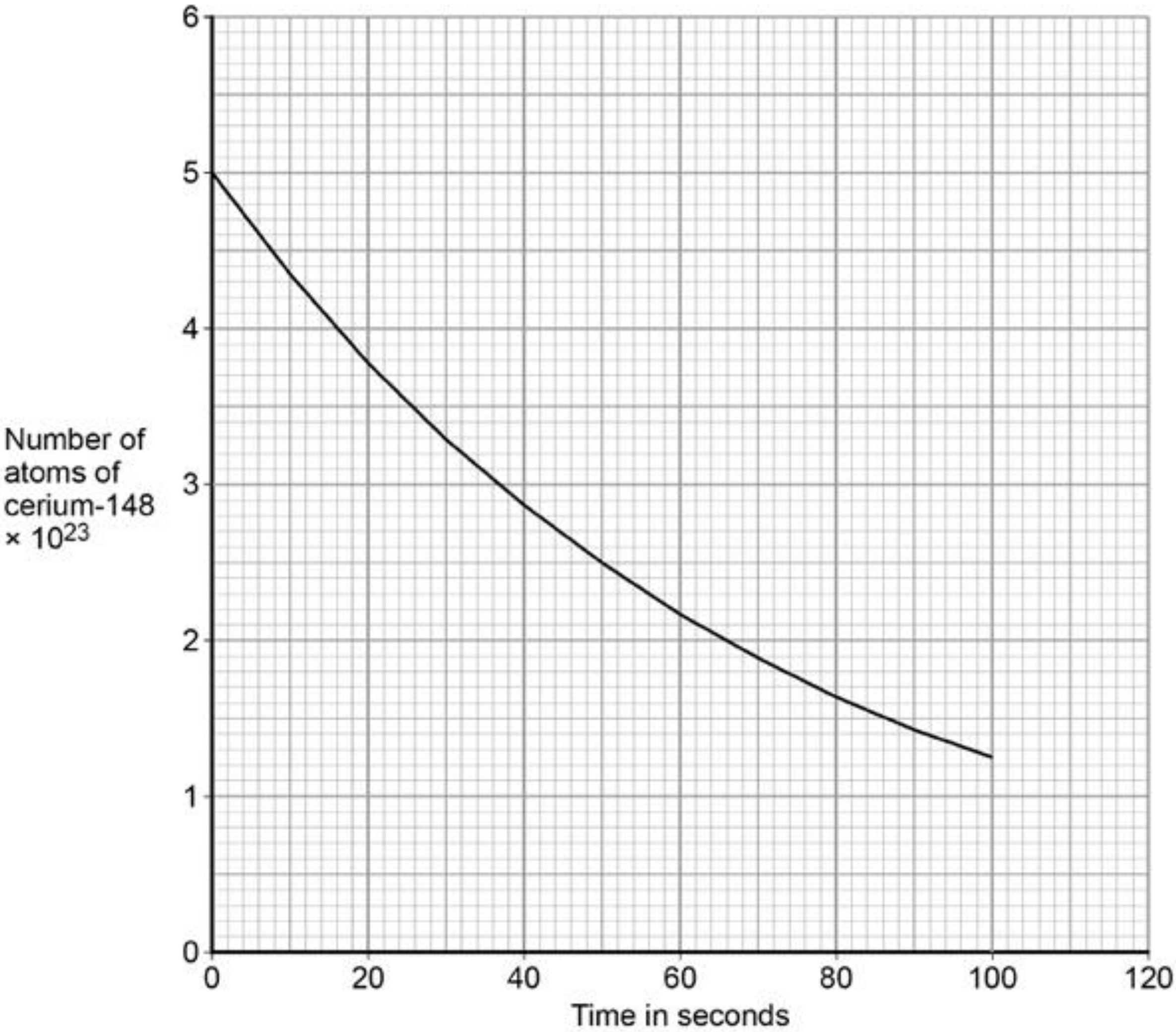
There are other isotopes of cerium which are radioactive.

Different isotopes of cerium have different half-lives.

The half-life of an isotope can be found by studying how the number of atoms changes over time.

Figure 2 shows how the number of atoms of cerium-148 in a 120 g sample changes over time.

Figure 2



(g) Determine the ratio of the number of cerium atoms in the sample when it was 100 seconds old compared with when the sample was 350 seconds old.

Use data from **Figure 2**.

____

____

____

____

____

____

____

____

Ratio = ____________________________

(4)

(h) Determine the activity of the sample of cerium when the sample was 20 seconds old.

Use **Figure 2**.

Activity = ______________________ Bq

(3)

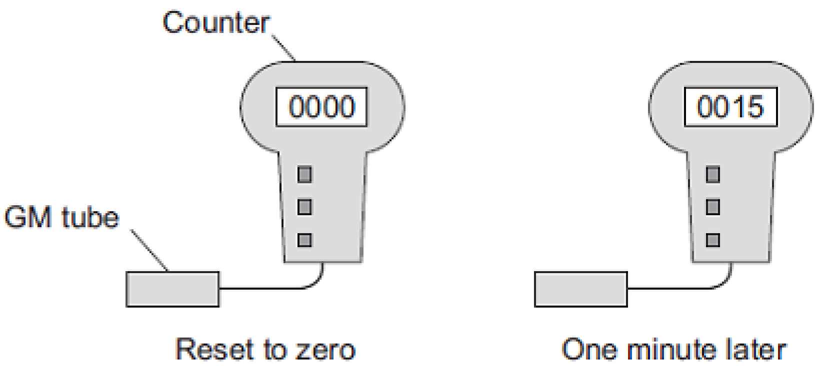
(Total 18 marks)

Triple Content

Q1.

(a) A teacher used a Geiger-Műller (GM) tube and counter to measure the *background radiation* in her laboratory.

The teacher reset the counter to zero, waited one minute and then took the count reading. The teacher repeated the procedure two more times.



(i) Background radiation can be either from natural sources or from man-made sources.

Name **one man-made** source of background radiation.

(1)

(ii) The three readings taken by the teacher are given in the table.

Count after one minute
15
24
18

The readings given in the table are correct.

Why are the readings different?

____

____

(1)

(b) Some scientists say they have found evidence to show that people living in areas of high natural background radiation are less likely to develop cancer than people living in similar areas with lower background radiation.

The evidence these scientists found does not definitely mean that the level of background radiation determines whether a person will develop cancer.

Suggest a reason why.

____

____

(1)

(c) An atom of the isotope radon-222 emits an alpha particle and decays into an atom of polonium.

An alpha particle is the same as a helium nucleus. The symbol below represents an alpha particle.

$$^{4}_{2}\mathrm{He}$$

(i) How many protons and how many neutrons are there in an alpha particle?

Number of protons = _________

Number of neutrons = _________

(2)

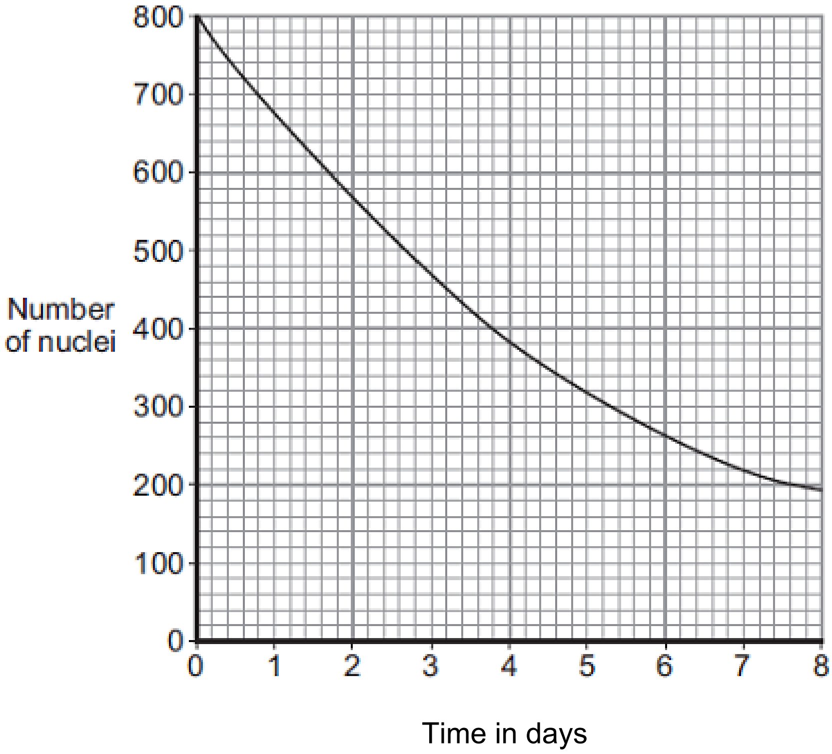
(ii) The decay of radon-222 can be represented by the equation below.

Complete the equation by writing the correct number in each of the **two** boxes.

$$^{222}_{86}\text{Rn} \longrightarrow {}^{\boxed{}}_{\boxed{}}\text{Po} + \text{alpha particle}$$

(2)

(d) The graph shows how, in a sample of air, the number of radon-222 nuclei changes with time.



Use the graph to find the half-life of radon-222.

Show clearly on the graph how you obtain your answer.

Half-life = ___________________________ days

(2)

(Total 9 marks)

Q2.

Radioactive waste from nuclear power stations is a man-made source of background radiation.

(a) Give **one** other man-made source of background radiation.

____

(1)

Nuclear power stations use the energy released by nuclear fission to generate electricity.

(b) Give the name of **one** nuclear fuel.

____

(1)

(c) Nuclear fission releases energy.

Describe the process of nuclear fission inside a nuclear reactor.

____

____

____

____

____

____

____

____

(4)

(d) A new type of power station is being developed that will generate electricity using nuclear fusion.

Explain how the process of nuclear fusion leads to the release of energy.

____

____

____

____

(2)

(e) Nuclear fusion power stations will produce radioactive waste. This waste will have a much shorter half-life than the radioactive waste from a nuclear fission power station.

Explain the advantage of the radioactive waste having a shorter half-life.

____

____

____

____

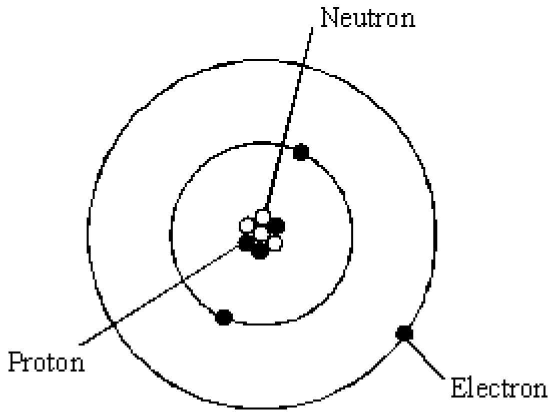
(2)

(Total 10 marks

Mark schemes

Q1.

(i) each correct label scores 1 mark



3

(ii) neutron 1

(iii) 7 1

number of protons and neutrons **or** number of nucleons or number of particles in the nucleus

accept number of particles in the centre only if first answer = 7

1

[6]

Q2.

(a) gamma 1

(b) alpha 1

(c) gamma 1

(d)

isotope	number of neutrons	number of protons	
uranium-238	146	**92**	1
thorium-234	**144**	90	1

(e) $\Delta\theta = 80\ °C$ 1

$E = 150 \times 4200 \times 80$ 1

E = 50 400 000 (J)

allow 50 000 000 (J) 1

*allow **max 2** marks for correct calculation using incorrect value of $\Delta\theta$*

*allow **1** mark for correct calculation using $\theta = 20$ **or** $\theta = 100$*

*an answer of 50 400 000 scores **3** marks*

[8]

Q3.

(a) $^{234}_{91}Pa$

1

(b) points correctly plotted to within 1 mm

1

a curved line of best fit passing within 1 mm of all 5 points

ignore any line beyond 200 seconds

1

(c) 70 (s)

allow an answer between 65 and 75 (s)

allow an answer consistent with their drawn line

1

(d) 70 (s)

allow an answer between 65 and 75 (s)

allow their answer to part (c)

1

(e) beta

1

(f) articles in scientific journals are peer reviewed

allow articles in scientific journals are based on evidence/data

allow newspaper articles may be oversimplified/inaccurate/biased

1

[7]

Q4.

any **two** pairs from:

to gain credit it must be clear which model is being described

*do **not** accept simple descriptions of the diagram without comparison*

- nuclear model mass is concentrated at the centre / nucleus (1)

  *accept the nuclear model has a nucleus / the plum pudding model does not have a nucleus for **1** mark*

  plum pudding model mass is evenly distributed (1)

- nuclear model positive charge occupies only a small part of the atom (1) plum pudding model positive charge spread throughout the atom (1)

- nuclear model electrons orbit some distance from the centre (1)

    accept electrons in shells / orbits provided a valid comparison is made with the plum pudding model

    plum pudding electrons embedded in the (mass) of positive (charge) (1)

    *do **not** accept electrons at edge of plum pudding*

- nuclear model the atom mainly empty space (1)

    plum pudding model is a 'solid' mass (1)

[4]

Q5.

(a) mass number stays the same, charge stays the same

1

(b) gamma radiation is only weakly ionising
or
most gamma radiation will pass through any detector

allow gamma radiation is very penetrating

1

(c) any two from

- the radiation spreads out in all directions
- only some of the radiation goes into the G-M tube
- only some of the radiation passing into the GM tube is detected

*allow **2** marks for only some of the radiation passing into the GM tube is detected because gamma is weakly ionising*

2

(d) to reduce the amount of radiation received

allow to reduce irradiation (of the teacher)

1

because radiation increases the risk of cancer or (genetic) mutation

allow causes cancer or (genetic) mutation

1

ignore references to contamination

(e) a calculation of the product of thickness and count rate

examples of calculations
0.5 × 110 = 55
1.0 × 60 = 60
1.5 × 33 = 50
2.0 × 18 = 36
2.5 × 10 = 25

1

a second calculation of the product of thickness and count rate

1

a comparison of the calculated values and a recognition that they are different

1

OR

A calculation of half the count rate (1)

e.g. $\frac{110}{2} = 55$

A comparison with the count rate for double that thickness (1)

the first two marks may be scored for a count rate divided by 3, 4 or 5 compared with the corresponding count rate for 3, 4 or 5 times the thickness

A recognition that the values are different (1)

e.g. $55 \neq 60$

(f)

$$^{140}_{57}\text{La} \longrightarrow {}^{0}_{-1}\text{e} + {}^{140}_{58}\text{Ce}$$

*allow **1** mark for correct numbers on electron*

*allow **1** mark for correct numbers on Ce*

2

(g) half-life = 50 seconds

*this may be indicated on **Figure 3***

1

250 seconds difference in age = 5 half lives

*allow 100 seconds = 2 half lives **and** 350 seconds = 7 half lives*

1

$\text{ratio} = \left(\frac{1}{2}\right)^5$

or

$\text{ratio} = \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2}$

allow this mark if they have halved 1.25(× 10^{23}) five times to get 0.0390625(× 10^{23})

for example 1.25(× 10^{23}) ⟶ 0.625(× 10^{23}) ⟶ 0.3125(× 10^{23}) ⟶ 0.15625(× 10^{23}) ⟶ 0.078125(× 10^{23}) ⟶ 0.0390625(× 10^{23})

1

ratio = $\frac{1}{32}$

or

ratio = 1:32

allow ratio = 0.031

*allow 32:1 **or** 32*

an answer of $\frac{1}{32}$ *or equivalent scores **4** marks*

1

(h) tangent drawn on graph

do not allow a line drawn that crosses the graph line

1

use of gradient = $\frac{(\Delta \text{ no. of atoms})}{\Delta \text{ time}}$

values must be taken from their tangent drawn at 20 seconds

1

gradient = 5.3 ($\times 10^{21}$) (Bq)

allow gradient =
0.053 (× 1023) (Bq)

allow a range between

4.7 ($\times 10^{21}$) (Bq) and 5.9 ($\times 10^{21}$) (Bq)

1

[18]

Triple Mark schemes

Q1.

(a) (i) any **one** from:

- nuclear power (stations)
  accept nuclear waste
  accept coal power stations
- nuclear weapons (testing)
  accept nuclear bombs / fallout
- nuclear accidents
  accept named accident, eg Chernobyl or Fukushima
  accept named medical procedure which involves a radioactive source
  accept radiotherapy
  accept X-rays
  accept specific industrial examples that involve a radioactive source
  nuclear activity / radiation is insufficient
  smoke detectors is insufficient

1

(ii) (radioactive decay) is a random process

accept an answer in terms of background / radiation varies (from one point in time to another)

1

(b) any **one** from:

- (maybe) other factors involved
  accept a named 'sensible' factor, eg smoking
- evidence may not be valid
  accept not enough data
- may not have (a complete) understanding of the process (involved)

1

(c) (i) 2

1

2

1

(ii) 218

correct order only

1

84

1

(d) 3.8 (days)

*allow **1** mark for showing correct method using the graph provided no subsequent steps*

*correct answers obtained using numbers other than 800 and 400 gain **2** marks provided the method is shown*

2

[9]

Q2.

(a) Any **one** from:

- (medical) x-rays
  allow CT scans
- radiotherapy
- nuclear weapons (testing)
  allow nuclear fallout
- named nuclear disaster e.g. Chernobyl / Fukushima / Three Mile Island.
  ignore radioactive / nuclear waste

1

(b) uranium / plutonium

ignore any number given

allow thorium

1

(c) neutron absorbed by a uranium nucleus

1

nucleus splits into two parts

allow an atom splits into two parts if 1st marking point doesn't score

1

and (2/3) neutrons (are released)

1

and gamma rays (are emitted)

1

(d) lighter nuclei join to form heavier nuclei

allow specific examples

1

some of the mass (of the nuclei) is converted to energy (of radiation)

1

(e) activity decreases quickly

allow nuclei / waste will decay at a greater rate
ignore waste is radioactive for less time

1

risk of harm decreases quickly

allow burial site doesn't need to be monitored for as long
or
doesn't need to be buried underground for as long
or
may not need to be buried underground

1

[10]