Question 1

Explain the underlined terms.

a self-sustaining reaction / a reaction where the release of one or more neutrons causes further fission **(3)**

fission is the splitting of a large nucleus **(3)**

into two (smaller) nuclei with the release of energy/neutrons *(−1 if atom used)* **(3)**

A substance called a moderator is mixed with the fuel in a nuclear reactor. Control rods are used to control the rate of the reaction.

Give an example of a moderator.

graphite / (heavy) water **(3)**

Explain (*i*) why a moderator is needed in a nuclear reactor and (*ii*) how the control rods affect the rate of the reaction.

(i) to slow down neutrons / so as to increase the probability of fission **(6)**

(ii) by absorbing neutrons **(6)**

A heat exchanger is used in a nuclear reactor.

Explain how the heat exchanger operates. Why is it necessary to use a heat exchanger?

heat/energy from reactor **(3)**

transfers to liquid/water in heat exchanger (to drive a turbine) **(3)**

the material in a reactor is radioactive / allows the core to reach a higher temperature **(4)**

Plutonium is produced in a fission reactor when one of the neutrons released in the fission reaction converts uranium–238 into plutonium–239 with the emission of two beta-particles.

Write an equation for this nuclear reaction.

$^{238}_{92}U + ^{1}_{0}n \rightarrow ^{239}_{94}Pu + 2\,^{0}_{-1}\beta$ *(–3 for extra particles)* **(10 × 1)**

Each fission of a uranium–235 nucleus produces 202 MeV of energy. Only 35% of this energy is used to generate electricity. How many uranium–235 nuclei are required to undergo fission to generate a constant electric power of 1 GW for a day?

Each fission = $(202 \times 10^{6})(1.6 \times 10^{-19})$ / 3.23×10^{-11} J **(3)**

35% of 202 MeV = 1.13×10^{-11} J **(3)**

1 GW for a day = 8.64×10^{13} J **(3)**

7.65×10^{24} nuclei **(3)**

Question 2

Energy can be produced in a fusion reaction by combining a deuterium and a tritium nucleus as follows:

$$^{2}_{1}\mathrm{H} + ^{3}_{1}\mathrm{H} \rightarrow ^{4}_{2}\mathrm{He} + \mathrm{n} + \text{energy}$$

(i) **Distinguish between nuclear fission and nuclear fusion.**

fission: large nucleus splits 3
into two smaller nuclei (of similar size) 3

fusion: two small nuclei join 3
to form a larger nucleus **(–1 if '*atoms*' referred to)** 3

(ii) **What are the advantages of fusion over fission in terms of fuel sources and reaction products?**

(hydrogen) fuel (from the sea) is plentiful – (uranium for fission is scarce) 6

no radioactive waste with fusion – (fission results in radioactive waste) 6

(iii) **How much energy is produced when a deuterium nucleus $^{2}_{1}\mathrm{H}$ combines with a tritium nucleus $^{3}_{1}\mathrm{H}$?**

(reactants:) 2.014102 + 3.016049 / 5.030151 3

(products:) 4.002603 + 1.008672 / 5.011275 3

Δm = 0.018875 u / 3.1344×10^{-29} kg 3

$E = mc^2$ 3

substitution 3

$E = 2.82(096) \times 10^{-12}$ J **(–1 for omission of or incorrect units)** 3

[If method used utilises: 1u ≡ 931 MeV ➔ $E = 2.81(17) \times 10^{-12}$ J]

(iv) **Calculate the force of repulsion between a deuterium and a tritium nucleus when they are 2 nm apart in free space.**

$F = \frac{q_1 q_2}{4\pi\varepsilon d^2}$ 3

$F = \frac{(1.602\times10^{-19})^2}{4\pi(8.854\times10^{-12})(2\times10^{-9})^2}$ 3

$F = 5.7(664) \times 10^{-11}$ N **(–1 for omission of or incorrect units)** 3

(v) **Fusion can only take place at very high temperatures. Explain why.**

nuclei must have very high speeds / energy if they are to combine /
to overcome force of repulsion between the nuclei 5

Question 3

(i) **Give one benefit of switching from fossil fuels to nuclear power for the generation of electricity. Explain your answer.**

more energy per kg / less carbon dioxide produced / production of useful radioisotopes *etc.* 4
explanation 3

Question 4

(b)

The following reaction occurs in a nuclear reactor:

$$^{235}\text{U} + {}^{1}_{0}\text{n} \rightarrow {}^{141}\text{Ba} + \text{X} + 3{}^{1}_{0}\text{n} + 202.5 \text{ MeV}$$

(i) Identify the element X.

Kr / krypton 6

[6]

(ii) Calculate the mass difference between the reactants and the products in the reaction.

$E = mc^2$ 3

$m = \dfrac{(202.5\times10^{6})(1.6\times10^{-19})}{(3\times10^{8})^{2}}$ 3

$m = 3.6\times10^{-28}$ kg 3

(–1 for omission of or incorrect units) [9]

(iii) What is a chain reaction?

self-sustaining reaction / reaction where fission neutrons produce further fission (giving more neutrons) etc./ clear diagrammatic representation 6

Give one condition necessary for a chain reaction to occur.

mass of fuel present exceeds the critical mass / at least one of the neutrons released must cause fission of another nucleus 3

[9]

(iv) Give one environmental impact associated with a nuclear reactor.

toxic /radioactive waste, exposure to radiation, etc. 4

Question 5

Question 11

Read the following passage and answer the accompanying questions.

The Miracle Year: 1905

"There is nothing new to be discovered in physics now," Lord Kelvin reportedly said in 1900. He was wrong.

Isaac Newton had laid the foundations of classical physics in the late seventeenth century. He developed laws that described a mechanical universe: a falling apple and an orbiting moon governed by the same rules of gravity, mass, force and motion. In the mid-1800s, Newtonian mechanics was joined by another great advance. Michael Faraday discovered the properties of electric and magnetic fields.

James Clerk Maxwell subsequently showed how changing electric and magnetic fields united to form electromagnetic radiation.

Physics was upended in the early twentieth century by Albert Einstein. In 1905 he devised a revolutionary quantum theory of light to explain the photoelectric effect, helped prove the existence of atoms, united the concepts of space and time, and produced science's best-known equation.

(Adapted from "Einstein: His Life and Universe"; Isaacson; 2007)

(*a*) The SI unit is named in honour of Lord Kelvin. What is the temperature of the boiling point of water in kelvin?

373(.15 K) 7

Question 11

Read the following passage and answer the accompanying questions.

At present, nuclear fission reactors supply a sixth of the world's electricity. Along with hydroelectric stations they are the major source of 'carbon-free' energy today. Nuclear reactors have shown remarkable reliability and efficiency even though the development of nuclear technology was held back by the nuclear accidents at Chernobyl and Three Mile Island.

A nuclear revival is possible. The global reserves of uranium could support a much larger number of reactors than exist today. Nuclear power generation could increase from three hundred gigawatts today to one thousand gigawatts by the year 2050, saving the earth from 1.5 billion tonnes of carbon emissions a year. Already more than twenty gigawatts of nuclear capacity have come online since 2000. Nuclear power would significantly contribute to the stabilisation of greenhouse gas emissions.

The type of reactor that will continue to dominate for the next two decades is the light water reactor, which uses ordinary water (as opposed to heavy water, containing deuterium) as the coolant and moderator.

Solar cells, wind turbines and biofuels are becoming viable energy sources. Solar cells use semiconductor materials, such as silicon, to convert sunlight into electricity, but at the moment they provide only 0.15% of the world's energy needs. Yet sunlight could be harnessed to supply 5000 times as much energy as the world currently consumes.

(Adapted from "Scientific American; Energy's Future beyond Carbon"; September 2006)

(a) **What is nuclear fission?**

disintegration / break-up / splitting of a large nucleus 4

into two smaller nuclei (+ neutrons + energy) **(-1 if** *atoms* **used; -1 if no comparative term used)** 3

(b) **How much energy is generated worldwide every minute by nuclear power today?**

$(300 \times 10^9)(60)$ J or 18,000 gigajoule (per minute) or 1.8×10^{13} J **(-1 for omission of or incorrect units)** 7

[stated or implied : power x time … 4 marks,]

(c) **At present, why is a fission reactor a more viable source of energy than a fusion reactor?**

(fission) can be (more) easily controlled / easier to initiate reaction **or** *vice versa* 7

(d) **Deuterium is an isotope of hydrogen; what is an isotope?**

atoms of the same element // atoms having the same atomic number / number of protons 4

having a different number of neutrons / (atomic) mass (or weight) / mass number 3

(e) **What is the function of a moderator in a fission reactor?**

to slow down (fast)neutrons (to facilitate fission) 7

(f) **Why is silicon a semiconductor?**

it has a resistivity / resistance / conductivity 4

between that of a conductor and an insulator 3

("it's neither a good conductor nor a good insulator"….. 7 marks)

(*R* decreases with (increasing) *T* 7 marks)

(g) **A large number of solar cells are joined together in series and cover an area of 20 m^2. The efficiency of the solar cell is 20%. If the solar constant is 1400 W m^{-2}, what is the maximum power generated by the solar cells?**

[1400×20 **or** $1400 \times {}^1/_5$) ….. 4 marks]

$(1400 \times 20 \times {}^1/_5)$ W **or** 5600 J s^{-1} **or** 5600 W **(-1 for omission of or incorrect units)** 7

(h) **What is the source of the sun's energy?**

fusion (reaction) / hydrogen (gas) 7

("nuclear reaction" …. 4 marks)

Question 7

(*c*) In 1939 Lise Meitner discovered that the uranium isotope U–238 undergoes fission when struck by a slow neutron. Barium–139 and krypton–97 nuclei are emitted along with three neutrons. Write a nuclear reaction to represent the reaction.

$^{238}_{92}U + ^{1}_{0}n \rightarrow ^{139}_{56}Ba + ^{97}_{36}Kr + 3\ ^{1}_{0}n$ **(-1 mark per each incorrect/omitted item)** 4×3

In a nuclear fission reactor, neutrons are slowed down after being emitted. Why are the neutrons slowed down?

(only) slow neutrons cause fission / to prevent (radiative) capture 6

How are they slowed down?

(they collide with) heavy water / a moderator / graphite 3

Fission reactors are being suggested as a partial solution to Ireland's energy needs. Give one positive and one negative environmental impact of fission reactors.

positive: no CO_2 emissions / no greenhouse gases / no gases to result in acid rain / less dependence on fossil fuels / etc.

negative: radioactive waste / (potential for) major accidents / etc.

(any order) 4+3

Question 8

Question 8
Distinguish between fission and fusion. (12)

fission is the splitting of a (large) nucleus 3
into two similar sized / smaller nuclei (with the emission of energy and neutrons) 3

fusion is the joining of two (small) nuclei 3
to form a larger nucleus (with the emission of energy) 3

The core of our sun is extremely hot and acts as a fusion reactor.
Why are large temperatures required for fusion to occur? (5)
nuclei are positively charged 3
(Coulomb / force of) repulsion must be overcome / large energy necessary to join them together 2

In the sun a series of different fusion reactions take place. In one of the reactions, 2 isotopes of helium, each with a mass number of 3, combine to form another isotope of helium with the release of 2 protons.
Write an equation for this nuclear reaction. (12)

correct equation 4 x 3

$$ {}^{3}_{2}He + {}^{3}_{2}He \rightarrow {}^{4}_{2}He + 2{}^{1}_{1}H $$

${}^{3}_{2}He$ (3)

${}^{4}_{2}He$ (3)

${}^{1}_{1}H (or\ {}^{1}_{1}p)$ (3)

Controlled nuclear fusion has been achieved on earth using the following reaction.

$$ {}^{2}_{1}H + {}^{3}_{1}H \longrightarrow {}^{4}_{2}He + {}^{1}_{0}n $$

What condition is necessary for this reaction to take place on earth?
Calculate the energy released during this reaction. (18)

large (initial) temperature / energy (required to start the reaction) 3

mass of reactants = 8.346×10^{-27} (kg): mass of products = 8.318×10^{-27} (kg) 3
loss in mass /defect mass = 2.8×10^{-29} kg 3
$E = mc^2$ 3
$E = (2.8 \times 10^{-29})(2.998 \times 10^{8})^2$ 3
$E = 2.5166 \times 10^{-12}$ J $\approx 2.52 \times 10^{-12}$ J **(-1 for omission of or incorrect unit)** 3

Give one benefit of a terrestrial fusion reactor under each of the following headings:
(i) fuel;
(ii) energy;
(iii) pollution. (9)

fuel: plentiful / readily available / cheap 3
energy: vast (energy released) / more (energy released gram for gram than from other sources) 3
pollution: no / little (radioactive) waste ; no / few greenhouse gases **(any one of these)** 3

(speed of light = 2.998×10^{-8} m s^{-1}; mass of hydrogen-2 nucleus = 3.342×10^{-27} kg ;
mass of hydrogen-3 nucleus = 5.004×10^{-27} kg; mass of helium nucleus = 6.644×10^{-27} kg;
mass of neutron = 1.674×10^{-27} kg)

Question 9

mostly empty space / dense core / positive core / electron cloud *(any two)* **(4 + 3)**

Question 10

9. **Define the becquerel.**

one disintegration per second 6

Name one device used to detect ionising radiations.

GM tube / solid state detector *etc.* 3

Compare alpha, beta, and gamma emissions using the following headings: (*a*) penetrating ability, (*b*) deflection in a magnetic field.

(*a*): gamma (most penetrating) > beta > alpha (least penetrating) 3

(*b*): alpha, beta deflected, gamma not deflected 3

alpha and beta deflected in opposite directions 3

The photograph shows one of the nuclear reactors at Chernobyl, where there was a fire in April 1986 that released large quantities of radioactive contaminants. Among the contaminants were iodine–131 and caesium–137, which are two of the unstable isotopes formed by the fission of uranium–235.

Explain what happens during nuclear fission.

large nucleus splits 3

into two smaller nuclei 3

with the emission of energy / neutrons 2

Iodine–131 decays with the emission of a beta-particle and has a half-life of 8 days.
Write an equation for the beta-decay of iodine–131.

$^{131}_{53}\mathrm{I} \rightarrow {}^{131}_{54}\mathrm{Xe} + {}^{0}_{-1}\mathrm{e}$ *(accept β for e)*

(1 mark for each correct number and symbol) 9×1

Estimate the fraction of the iodine–131 that remained after 40 days.

40 days = 5 half-lives 3

$(\frac{1}{2})^5$ / $\frac{1}{32}$ 3

Caesium–137 has a half-life of 30 years and it remains a significant contaminant in the region around Chernobyl. It is easily absorbed into the tissues of plants as they grow. Scientists collected a sample of berries growing near the abandoned power station. The activity of the sample was measured at 5000 Bq.
Calculate the decay constant of caesium–137.

$\lambda = \frac{\ln 2}{T_{\frac{1}{2}}}$ 3

$\lambda = 7.32 \times 10^{-10}\ \mathrm{s}^{-1}$ *(–1 for omission of or incorrect units)* 3

Hence calculate the number of caesium–137 atoms present in the sample. (You may assume that all of the activity was caused by caesium–137.)

$A = \lambda N$ 3

$N = 6.83 \times 10^{12}$ atoms 6

Question 11

(*a*) **List three quantities that are conserved in nuclear reactions.**

momentum, charge, mass-energy, nucleons, etc. (any *three* valid answers) 2+2+2

Write an equation for a nucleus undergoing beta-decay.

$^{228}_{88}X \rightarrow \, ^{228}_{89}Y + \, ^{0}_{-1}e$ 3×3

In initial observations of beta-decay, not all three quantities appear to be conserved. What was the solution to this contradiction?

<u>proposal</u>/<u>discovery</u> of the <u>neutrino</u>/ <u>υ</u> 3

List the fundamental forces of nature in increasing order of their strength.

gravitational < weak (nuclear) < electromagnetic < (strong) nuclear 3×3

(3 marks for naming any two; 2×3 marks for naming the correct four; 3 marks for <u>correct</u> order)

Which fundamental force of nature is involved in beta-decay?

weak (nuclear) 3

In the Large Hadron Collider, two protons with the same energy and travelling in opposite directions collide. Two protons and two charged pi mesons are produced in the collision. Why are new particles produced in the collision?

energy is converted into mass / $E = mc^2$ 3

Write an equation to represent the collision.

$$p + p \rightarrow p + p + \pi^+ + \pi^-$$ 3×3

(3 marks for showing 2 p before and after; 3 marks for showing two pions ; 3 marks for correct format)

Show that the kinetic energy of each incident proton must be at least 140 MeV for the collision to occur.

mass of $\pi^+ = 273\, m_e$ / $= 273(9.109 \times 10^{-31})$ kg 3

$E = mc^2$ 3

$E = 2(2.4869 \times 10^{-28})(3 \times 10^8)^2$ / 44.76×10^{-12} J 3

$\mathrm{E} = \dfrac{44.76 \times 10^{-12}}{1.602 \times 10^{-19}}$ / $\approx 279.94 \times 10^6$ eV / ≈ 280 (MeV) 3

energy per proton = 140(MeV) 2

Question 12

(*d*) In the manufacture of newsprint paper, heavy rollers are used to adjust the thickness of the moving paper. The paper passes between a radioisotope and a detector, and a pair of rollers, as shown.

(i) Name a suitable detector.

solid state detector / GM tube (linked with a ratemeter/scaler) 6

(ii) Describe how the reading on the detector may vary as the paper passes by.

(count rate) would decrease 3

with increasing paper thickness 6

(or vice versa)

(iii) Why would the radioisotope Am-241, which emits alpha-particles, not be suitable for this process?

paper would (easily) block alpha-particles / alpha-particles have poor penetrating power 4

(iv) Calculate the number of atoms present in a sample of Sr-90 when its activity is 4250 Bq. The half-life of Sr-90 is 28.78 years. (Accept: 1 year = 365 days or 365.25 days)

$\lambda T_{\frac{1}{2}} = 0.693$ / $\lambda = 7.77\times10^{-10}\ s^{-1}$ / $\lambda = 7.63\times10^{-10}\ s^{-1}$ 3

activity $\left(= \frac{dN}{dt}\right) = (-)\lambda N$ / $4250 = \left(7.77\times10^{-10}\right)N$ / $4250 = \left(7.63\times10^{-10}\right)N$ 3

$N = 5.47\times10^{12}$ (atoms) / 5.57×10^{12} (atoms) 3

Question 13

What is thermionic emission?

the emission of electrons 3
(from the) surface of a hot metal 3

6

X-rays are produced when high-energy electrons collide with a target.
Draw a labelled diagram of an X-ray tube.

vacuum 3
cathode 3
target / anode 3
high (accelerating anode) voltage or H.T. / shielding / cooling / low (cathode) voltage or L.T. 3

12

What are X-rays and how do they differ from light rays?

<u>what</u>: electromagnetic radiation / photons / quanta of energy 6

high frequency / short wavelength / high energy 3

<u>how</u>: x-rays penetrate matter / cause ionization / any valid comparative property 3

Give two uses of X-rays.

(medical) analysis of bone structure/ luggage scanners (at airports) / any specific medical,

industrial or security use, etc. <u>any two</u> 2×3

18

When electrons hit the target in an X-ray tube, only a small percentage of their energy is converted into X-rays. **What happens to the rest of their energy and how does this influence the type of target used?**

converted to heat 6
target material must have (very) high melting point / (specific example, e.g.) tungsten 3

9

A potential difference (voltage) of 40 kV is applied across an X-ray tube.

Calculate:

(i) the maximum energy of an electron as it hits the target

$W = qV$ 3

$W = \left(1.6\times10^{-19}\right)\left(40\times10^{3}\right) / = 6.4\times10^{-15}$ J 3

(–1 for omission of or incorrect units)

(ii) the frequency of the most energetic X-ray produced.

$E = hf$ 3

$f = \dfrac{6.4\times10^{-15}}{6.6\times10^{-34}}$ / = 9.7×10^{18} Hz 2

(–1 for omission of or incorrect units)

11

Question 12 (d)

Smoke detectors use a very small quantity of the element americium -241.
Alpha particles are produced by the americium-241 in a smoke detector.

(i) Give the structure of an alpha particle.

2 protons and 2 neutrons // helium nucleus // ${}^{4}_{2}He$ // He^{++} 3

(ii)

(iii) How are the alpha particles produced?

(americium) is radioactive / unstable /disintegrates /undergoes α-decay 6

(iii) Why do these alpha particles not pose a health risk?

very short range / poor penetrators / neutralised (to form helium)
trapped within smoke detector **(any one reason)** 4

13

Americium-241 has a decay constant of 5.1 × 10^{-11} s^{-1}. Calculate its half life in years.

$\lambda T_{\frac{1}{2}} = 0.693$ 3

$T_{\frac{1}{2}} = \frac{0.693}{5.1\times10^{-11}}$ 3

$T_{\frac{1}{2}} =$ (1.36×10^{10} s =1.573×10^{5} days =) 430.6 years **(–1 if answer not in years)** 3

9

Explain why americium-241 does not exist naturally.

not a member of a decay series / half life is short (w.r.t. age of universe - state/imply) / any reference to *synthetic/artificial* / no natural parent **(any *one*)** 6

6

Question 10 (a) **Answer either part *(a)* or part *(b)*.**

Read the following passage and answer the accompanying questions.

Ernest Walton was one of the legendary pioneers who made 1932 the *annus mirabilis* of experimental nuclear physics. In that year James Chadwick discovered the neutron; Carl Anderson discovered the positron; Fermi articulated his theory of radioactive decay; and Ernest Walton and John Cockcroft split the nucleus by artificial means. In their pioneering experiment Cockcroft and Walton bombarded lithium nuclei with high-energy protons linearly accelerated across a high potential difference (*c.* 700 kV). The subsequent disintegration of each lithium nucleus yielded two helium nuclei and energy. Their work gained them the Nobel Prize in 1951.

(Adapted from "Ernest Thomas Sinton Walton 1903 –1995 The Irish Scientist" McBrierty; 2003)

(i) Draw a labelled diagram to show how Cockcroft and Walton accelerated the protons.

anode and cathode (in tube) / (lithium) target / two helium nuclei 3

p.d / V / H.T 3

What is the velocity of a proton when it is accelerated from rest through a potential difference of 700 kV?

$W = qV$ 3

$W = \frac{1}{2}mv^2$ 3

$$v^2 = \frac{2(1.6022\times10^{-19})(7.00\times10^5)}{1.6726\times10^{-27}}$$ 3

$\Rightarrow v = 1.16 \times 10^7$ m s^{-1} **(-1 for omission of or incorrect units)** 3

Write a nuclear equation to represent the disintegration of a lithium nucleus when bombarded with a proton.

$^7_3Li + ^1_1H \rightarrow 2\,^4_2He$ **(accept *p* for *H* and α for *He* ; -1 for each error)** 3 x 3

Calculate the energy released in this disintegration.

mass of reactants = $1.1646 \times 10^{-26} + 1.6726 \times 10^{-27}$ or 1.33186×10^{-26} (kg) 3

mass of products = $2(6.6443 \times 10^{-27})$ or 1.32886×10^{-26} (kg) 3

$\Delta m = 3.00 \times 10^{-29}$ kg 3

$E = mc^2$ or $E = (3.00 \times 10^{-29})(9 \times 10^{16})$ or $E = 2.7 \times 10^{-12}$ J 3

(-1 for omission of or incorrect units)

(ii) Compare the properties of an electron with that of a positron.

(both have) equal mass / charges equal / charges opposite (in sign) / matter and anti-matter

any *one* direct comparison 5

What happens when an electron meets a positron?

(pair) annihilation / energy released(or produced) / γ-rays emitted 3

(iii) In beta decay it appeared that momentum was not conserved.
How did Fermi's theory of radioactive decay resolve this?

any reference to *neutrino* 6

(neutrino had the *missing*) momentum 3

(charge on electron = 1.6022×10^{-19} C; mass of proton = 1.6726×10^{-27} kg;
mass of lithium nucleus = 1.1646×10^{-26} kg; mass of helium nucleus = 6.6443×10^{-27} kg;
speed of light = 2.9979×10^8 m s^{-1})

Question 16

(*i*) **Name an instrument used to detect radioactivity.**
What is the principle of operation of this instrument?

GM-tube	// Cloud/ionisation chamber	// solid state detector	4
ionization	// condensation/ cloud formation/ionization	// (formation) of ion-pairs	3

Question 17

Question 12 (d)
Explain the term half-life.

time // $\lambda T_{\frac{1}{2}} = 0.693 (= \ln 2)$ 3

for half (the radioactive nuclei in a sample) to decay / for activity (of a sample) to be halved // λ a constant 3

A sample of carbon is mainly carbon-12 which is not radioactive, and a small proportion of carbon-14 which is radioactive. When a tree is cut down the carbon-14 present in the wood at that time decays by beta emission.
Write a nuclear equation to represent the decay of carbon-14.

$${}^{14}_{6}C \rightarrow {}^{0}_{-1}\beta + {}^{14}_{7}N$$ 3 x 3

(accept e in lieu of β …. –1 for each error)

An ancient wooden cup from an archaeological site has an activity of 2.1 Bq. The corresponding activity for newly cut wood is 8.4 Bq. If the half-life of carbon-14 is 5730 years, estimate the age of the cup.

(8.4 Bq → 2.1 Bq requires) two half-lives. 3
11,460 years 3

Name an instrument used to measure the activity of a sample. What is the principle of operation of this instrument?

Geiger Counter / GM tube:	(gas is) ionised (and a pulse of charge/current flows)	
ratemeter :	average number of particles / current detected or displayed	
scaler:	total number of particles / pulses of charge is counted or displayed	
solid state detector:	electron-hole pairs created	
etc.	(for any one instrument + principle)	6 + 1

Question 18

(*i*) **Describe the Bohr model of the atom.** (7)

nucleus (any reference) 4
electrons in orbit / shells / energy levels 3

Question 19

(j) Name the fundamental force of nature that holds the nucleus together.
Or
Draw the truth table for the AND gate. (7)

strong // 0-1; 1-0; 0-0 gives 0 (output) 4

nuclear // 1-1 gives 1 (output) 3

Question 20

Question 8

Nuclear disintegrations occur in radioactivity and in fission.

Distinguish between radioactivity and fission. (12)

radioactivity is the disintegration of an (unstable) nucleus	3
with the emission of α / β / γ / radiation	3
fission is the splitting of a (large) nucleus	3
into two similar sized / smaller nuclei with the release of energy and neutrons	3

Give an application of (i) radioactivity, (ii) fission. (6)

(i) smoke detectors, carbon dating, tracing leaks, medical (cancer treatment, sterilising), etc.	3
(ii) generating electrical energy / power, bombs	3

Radioactivity causes ionisation in materials. What is ionisation? (3)

the charging of a (neutral) atom / (when) atom loses (or gains) electron(s)

/ atom (formed) with unequal number of + and - (charges) 3

Describe an experiment to demonstrate the ionising effect of radioactivity. (12)

apparatus // radioactive source and charged (gold leaf) electroscope	3
procedure // bring radioactive source close to the cap	3
observation // leaves collapse	3
conclusion //as charge leaks away through ionised air / electroscope neutralised by ionised air	3

Cobalt–60 is a radioactive isotope with a half-life of 5.26 years and emits beta particles.

(i) Write an equation to represent the decay of cobalt–60. (9)

$${}^{60}_{27}Co \rightarrow {}^{0}_{-1}e + {}^{60}_{28}Ni$$

(each incorrect item .. –3) 3×3

(numbers consistently inverted or placed to the left, right or alternate side of symbol, acceptable.)

(ii) Calculate the decay constant of cobalt–60. (8)

formula: $\lambda T_{½} = \ln 2$	3
correct substitution (i.e. $T_{1/2}$ = 5.26 y / 1.66×10^{8} s and ln 2 = 0.693)	3
answer: $\lambda = 4.18 \times 10^{-9}$ s^{-1} / 3.61×10^{-4} days^{-1} / 0.132 y^{-1}	2

(-1 for omission of or incorrect unit)

(iii) Calculate the rate of decay of a sample of cobalt–60 when it has 2.5×10^{21} atoms. (6)

activity / A / dN/dt = (-)λN 3

= 1.04 (5) $\times 10^{13}$ Bq (or s^{-1}) (-1 for omission of or incorrect unit) 3

(decay w.r.t. years => 3.30×10^{20} y^{-1})

Question 21

(i) What is the structure of an alpha particle? (7)

Two protons	// helium	4
two neutrons	// nucleus (in context)	3

(ii) Rutherford had bombarded gold foil with alpha particles. What conclusion did he form about the structure of the atom? (7)

(dense) positive core / nucleus	4
(atom) mostly empty space / radius of nucleus $\approx 10^{-15}$ m / radius of atom $\approx 10^{-10}$ m	3

(iii) High voltages can be used to accelerate alpha particles and protons but not neutrons. Explain why. (7)

alpha particles and protons are charged	4
neutrons are not charged	3

(iv) Cockcroft and Walton, under the guidance of Rutherford, used a linear particle accelerator to artificially split a lithium nucleus by bombarding it with high-speed protons.

Copy and complete the following nuclear equation for this reaction. (7)

${}^{4}_{2}He$	4
${}^{4}_{2}He$	3

(v) Circular particle accelerators were later developed. Give an advantage of circular accelerators over linear accelerators. (7)

(progressively) increasing (or more) energy/speed attainable / more compact / occupy less space	any one	7

(vi) In an accelerator, two high-speed protons collide and a series of new particles are produced, in addition to the two original protons. Explain why new particles are produced. (7)

(kinetic) energy (of the protons)	4
converted into mass (of new particles)	3

(vii) A huge collection of new particles was produced using circular accelerators. The quark model was proposed to put order on the new particles. List the six flavours of quark. (7)

Up, down, charm, strange, top, bottom	$(6 \times 1) + 1$

(viii) Give the quark composition of the proton. (7)

Up, up, down	h/m	7