Nuclear Decay MS

1. B

[1]

2. (a) β-particles can (easily) penetrate the body/skin **(1)**

Since they are not very ionising OR reference to what will stop them **(1)** 2

(b) (i) Use idea that number of unstable atoms halves every 8 days OR that 24 days represents 3 half-lives **(1)**

Correct answer **(1)**

Example calculation:

$$N_0 \rightarrow \frac{N_0}{2} \rightarrow \frac{N_0}{4} \rightarrow \frac{N_0}{8}$$

$$t = 0 \qquad t = t_{1/2} \qquad t = 2t_{1/2} \qquad t = 3t_{1/2}$$

Fraction decayed = 100% - 12.5% = 87.5% 2

(ii) Use of $\lambda\, T_{1/2} = \ln 2$ **(1)**

Use of an appropriate decay equation **(1)**
Correct answer **(1)** 3

Example of calculation:

$$\lambda = \frac{\ln 2}{T_{1/2}} = \frac{0.693}{8\,\text{day}} = 0.0866\,\text{day}^{-1}$$

$$1.50\text{MBq } A_0 \; e^{-0\ 0866\ \text{day}^{-1} \times 1\text{day}}$$

$$A_0 = 1.50\text{MBq}e^{0.0866} = 1.64\text{ MBq}$$

[7]

3. (a) Alpha-radiation only has a range of a few cm in air / cannot penetrate walls of container / skin **(1)** 1

(b) (i) Top line: ^{241}Am ^{237}Np $^{4}\alpha$ **(1)**

Bottom line: $_{95}Am$ $_{93}Np$ $_{2}\alpha$ **(1)** 2

(ii) Attempt at calculation of mass defect **(1)**

Use of $(\Delta)E=c^2(\Delta)m$ OR use of 1 u = 931.5 MeV **(1)**

Correct answer [5.65 MeV; accept 5.6 – 5.7 MeV] **(1)**

Example of calculation:
$\Delta m = 241.056822u - 237.048166u - 4.002603u - 0.006053\ u$

$\Delta m = 0.006053u \times 1.66 \times 10^{-27}\ kgu^{-1} = 1.005 \times 10^{-29}\ kg$

$E = 1.005 \times 10^{-29}\ kg \times (3 \times 10^8\ ms^{-1})^2 = 9.04 \times 10^{-13}\ J$

$E = \dfrac{9.04 \times 10^{-13}\ J}{1.6 \times 10^{-13}\ MeVJ^{-1}} = 5.65MeV$ 3

(c) Reference to half-life and typical lifespan 1

[7]

4. C

[1]

= 5.65MeV 3

(c) Reference to half-life and typical lifespan 1

[7]

5. (a) use of counter (+GM tube)
determine background count in absence of source
place source **close** to detector and:
place sheet of paper between source and counter (or increase distance
from source 3-7 cm of air) reduces count to background 4

(b) alpha radiation only has range of 5 cm in air / wouldn't get through casing **(1)** 1

[5]

6. (a) 19 protons identified **(1)**
calculation of mass defect **(1)**
Conversion to kg**(1)**
use of E = mc2 **(1)**
divide by 40**(1)**
$= 1.37 \times 10^{-12}$ J**(1)**

[eg 19 × 1.007276 = 19.138244 + 21 × 1.008665 = 40.320209 – 39.953548 = 0.36666

$\times 1.66 \times 10^{-27} = 6.087 \times 10^{-28}$
$\times c^2 = 5.5 \times 10^{-11}$
$/40 = 1.37 \times 10^{-12}$ J] 6

(b) cannot identify which atom/nucleus will be the next to decay
can estimate the fraction /probability that will decay in a given time /
cannot state exactly how many atoms will decay in a set time 1

(c) (i) conversion of half life to decay constant
[eg $\lambda = \ln 2 / 1.3 \times 10^9 = 5.3 \times 10^{-10}$ y^{-1}] 1

(ii) add both masses to find initial mass **(1)**
use of $N = N_o e^{-\lambda t}$ **(1)**
rearrange to make t subject **(1)**
Answer = 4.2×10^9 years **(1)**
(if 0.84 used instead of 0.94 3 max)
[eg total initial mass 0.94
$t = \ln 0.1 / 0.94 / 5.3 \times 10^{-10}$
$= 4.2 \times 10^9$] 4

[12]

7. (a) Show that rate of decay of radium is about 7×10^{13} Bq
Power divided by alpha particle energy **(1)**

Answer [(7.1 – 7.2) × 10^{13} (Bq)] **(1)**

[Give 2 marks for reverse argument ie
7 × 1013 Bq × 7.65 × 1013 J **(1)**
(53.5 – 53.6) (W) **(1)**]

Eg Rate of decay = $\dfrac{55\text{ W}}{7.65 \times 10^{-13}\text{ J}}$
= 7.19 × 1013 (Bq) 2

(b) Show that decay constant is about 1.4×10^{-11} s^{-1}

Use of $\lambda = \dfrac{0.69}{T_{1/2}}$ **(1)**

Answer [(1.35 – 1.36) × 10^{-11} (s^{-1})] **(1)**

Eg $\lambda = \dfrac{0.69}{1620 \text{ years} \times 3.15 \times 10^{7} \text{ s}}$

= 1.35×10^{-11} (s^{-1}) 2

(c) <u>The number of radium 226 nuclei</u>

Use of A = λN **(1)**

Answer [(5.0 – 5.4) × 10^{24}] **(1)**

Eg 7.19×10^{13} Bq = 1.35×10^{-11} s^{-1} × N

N = 5.33×10^{24} 2

(d) The mass of radium

Divides number of radium 226 nuclei by 6.02×10^{23} and multiplies by 226 **(1)**

Answer [1870 – 2040 g]

Eg Mass of radium = 226 g × $\dfrac{5.33 \times 10^{24}}{6 \times 10^{23}}$

= 2008 g 2

(e) <u>Why mass would produce more than 50 W</u>

The (daughter) nuclei (radon) formed as a result of the decay of radium are themselves a source of (alpha) radiation / energy **(1)**

Also accept

(having emitted alpha) the nucleus[allow sample/radium/atom] (maybe left excited and therefore also) emits gamma

Also accept

(daughter) nucle(us)(i) recoil releasing (thermal) energy

Do not accept

Nucleus may emit more than one alpha particle

Nucleus may also emit beta particle 1

[9]

8. (a) Change in nuclear composition

- Nucleus has one less neutron OR nucleus has one more proton) 1

(b) (i) Calculation of age of skull

- Use of $\lambda = \ln 2/t_{½}$ to obtain value for λ
- Use of $N = N_o e^{-\lambda t}$
- Correct answer for age of skull [1.2×10^4 y; 3.83×10^{11} s]

Example of calculation:

$\lambda = \ln 2/t_{½} = \ln 2/5730 \text{ y} = 1.2 \times 10^{-4} \text{ y}^{-1}$ [$3.84 \times 10^{-12} \text{ s}^{-1}$]

$\ln(N/N_o) = -\lambda t$

$\ln(2.3 \times 10^{-11}/1.0 \times 10^{-10}) = -(1.2 \times 10^{-4} \text{ y}^{-1})t$

$t = 1.2 \times 10^4$ y

Alternative mark scheme

- Use of half life rule
- Correct answer for number of half lives [2.12]
- Correct answer for age of skull [1.2×10^4 y]

Example of calculation:

$N/ N_o = (0.5)n$

$(2.3 \times 10^{-11})/(1 \times 10^{-10}) = (0.5)n$

$\log(0.23) = n \log(0.5)$

$n = \log(0.23)/\log(0.5) = 2.12$

$t = 2.12 \times 5730 = 1.2 \times 10^4$ y 3

(ii) Reason for inaccuracy

- Idea that it is impossible to know the exact proportion of ^{14}C in the atmosphere when the bones were formed OR reference to the difficulty of measuring such small percentages of ^{14}C. 1

(iii) Why 210Pb is more suitable:

- Idea that the half life of 210Pb is closer to the age of recent bones [e.g. a greater proportion of 210Pb will have decayed as the time elapsed is one or more half lives] 1

[6]

9. (a) $^{18}_{8}O + ^{1}_{1}p/H$ equals $^{18}_{9}F + ^{1}_{0}n$ **(1)** **(1)** **(1)**

[omitting the n with everything else correct = 1] 3

(b) Accelerated through 19×10^6 V / MV

Using linear accelerator / cyclotron / particle accelerator / **(1)**

recognisable description **(1)** 2

(c) Time taken for half the original quantity/ nuclei /activity to decay **(1)**

Long enough for (cancer/tumour/body to absorb) and still be active/detected **(1)**

Will not be in body for too long **(1)** 3

(d) Use of $E = mc^2$ **(1)**
Use of $E = hf$ **(1)**
Use of $v = f\lambda$ **(1)**
$\lambda = 2.4 \times 10^{-12}$ m **(1)**

eg $9.11 \times 10^{-31} \times 9 \times 10^{16}$ (×2)
$f = 8.2 \times 10^{-14} / 6.6 \times 10^{-34}$ ecf
$\lambda = 3 \times 10^{8} / 1.2 \times 10^{20}$ ecf 4

(e) Conservation of momentum **(1)**

Before momentum = 0 **(1)**

so + for one photon and – for other **(1)** 2 max

[14]

10. (a) <u>How a beta-minus particle ionises</u>
When a beta particle removes [accept repel] an <u>electron</u> from an atom / molecule **(1)** 1

(b) <u>How ionisation determines range</u>
State that each ionisation requires energy **(1)**
The energy (to ionise) is obtained from the (transfer of) (kinetic) energy of the beta particle (which is therefore reduced) **(1)**
Along its path it produces many ionisations until all its (kinetic) energy is used up **(1)**
The more ionising a particle the shorter its range or the less ionising the greater the range **(1)**
[Candidates may give the wrong reason for ionisation or even compare alpha and beta but still award this mark.]
Max 3 marks from 4

[Note that the word ¯kinetic¯ is not essential for marks 2 and 3] 3

(c) Why more ionisation is produced towards the end of its range
(Towards the end of its range) the beta particle is travelling slower or has less kinetic energy (than at the beginning of its range) **(1)**
(as a result it takes longer travelling a given length) and therefore has **more** (close) **encounters** with atoms / molecules
or more **opportunities** to ionise (atoms / molecules)
or will remain in contact (with atoms / molecules) longer
or will **collide** with more (atoms / molecules per unit length)
or ionisation (of atoms/molecules) is more **frequent** (towards end of range) **(1)** 2

[6]

11. (a) Meanings
Spontaneous: Happens independently of/cannot be controlled by/ unaffected by chemical conditions/physical conditions/temperature/ pressure or without stimulation/without trigger. **(1)**

[Do not accept random/cannot be predicted]

Radiation: alpha, beta and gamma and positron
[give the mark if they name **one** of these] **(1)**

Unstable: (Nuclei) [**not atoms**] are (liable) to break up / decay / disintegrate or nucleus has too much energy or too many nucleons [not particles]/may release radiation/[Accept] binding force is not sufficient/[Accept] binding energy is not sufficient/ [Accept] too many/too few protons/neutrons **(1)**

[For this mark do not accept ‘nucleus has high energy’ or ‘..has many particles’] 3

(b) (i) Half life

Evidence of an average calculated ie have used more than just one value **(1)**

[Make sure to look at graph, if 2 sets of lines are seen, award this mark, even if there is no evidence in written answer]

Answer [(5.6 – 6) hours (20160 s – 21600 s)] **(1)** 2

(ii) Decay constant
Answer [Accept answers in the range 3.1 – 3.5 × 10^{-5} s^{-1} / 0.11(5) – 0.12(3) h^{-1}] **(1)** 1

[ecf their value of half life]

[Do not accept Bq for the unit]

Eg $\lambda = \dfrac{0.69}{6 \times 3600\,\text{s}} / \dfrac{0.69}{6\,\text{h}} = 3.19 \times 10^{-5}\ \text{s}^{-1} / 0.12\ \text{h}^{-1}$

(iii) Number of atoms
Use of $|A| = \lambda N$
Answer [in range (1.50 – 1.65) × 10^{11}]

Eg $N = \dfrac{0.5 \times 10^{7}\ \text{Bq}}{3.2 \times 10^{-5}\ \text{s}^{-1}}$
$= 1.56 \times 10^{1}$ 2

[8]

12. (a) Meaning of 'random'
Impossible to predict which atom/nucleus (in a given sample) will decay (at any given moment)/ unable to predict when a given atom will decay **(1)**
[Mention of atom(s), or nucleus, or nuclei is essential because the word 'random' is to be described in context. Do not accept for atom or nucleus; substance; material; particle; molecule; sample.] 1

(b) Nuclear equation
$^{241}_{95}\text{Am} \rightarrow ^{237}_{93}\text{Np} + ^{4}_{2}\text{He}$
$^{4}_{2}\text{He}$ or $^{4}_{2}\alpha$ **(1)**
$^{241}_{95}\text{Am}$ / $^{237}_{93}\text{Np}$ / both proton numbers correct / both mass numbers correct **(1)**
Entirely correct equation **(1)** 3

(c) Absorbtion experiment
Diagram [must include the source, detector and an indication of where the absorber is placed (maybe written in their account rather than on the diagram) – none of these need to be labelled] **(1)**
(Record) background count **(1)**

Source – detector distance must be close / less than or equal to 2 cm **(1)**

Insert eg paper between source and detector = no change in count rate or increase (by a small amount) the separation of the detector and source = no change in count rate (therefore no α present) **(1)**

Insert aluminium/brass (a few mm thick) or lead (≈ 2mm thick) / concrete **(1)**

Count reduced to background (therefore no gamma present)
[Do not give this mark if only paper or card or plastic is used as the absorber. Accept '0' in place of 'reduced to background' if candidate has deducted background from their measurements.] **(1)** Max 5

[9]

13. (i) Plot a graph

Check any 2 points.
[Award if these correctly plotted in appropriate square] **(1)**
Curve of best fit. **(1)** 2

(ii) Half life average time required **(1)**
for the count rate / activity / intensity to reach half the original value or time taken for half of the atoms / nuclei/nuclides to decay **(1)**
[NOT mass / particles / atom / (radio)isotope / count / sample/ cells/ nuclide]

(iii) Use the graph
Value of half life [Allow answers in the range 3.1 – 3.3. **(1)**
Mark not to be awarded if a straight lined graph was plotted]
Two or more sets of values used to find half life.
[Could be shown 1 on graph] **(1)** max 3 (ii &iii)

(iv) Similar to
eg (The programme) obeys an exponential law or once a cell has 'decayed', it is not available to decay later **or** (the 'decay' is) random **or** it is impossible to predict which cell will 'decay' next. **(1)** 1

(v) Different
eg (Far) fewer cells available than atoms (in a sample of radioactive material) or it is a different 'scenario' eg. they are not atoms but cells on a grid generated by computer. **(1)** 1

[7]

14. Proton numbers:

55 and 94 **(1)** 1

Fuel for the power station:
(i) (Nuclear) fission (of ^{235}U) **(1)**
(ii) Absorption of a neutron by(^{238})U(followed by β-decay) **(1)** 2
[**not** bonding, **not** fusion, allow combining] [Any other particle mentioned in addition to neutron loses the mark]

Calculate emission rate:
Use of $\lambda = \ln 2 / t_{½}$ [allow either Cs $t_{½}$] **(1)**
See $1.5 \times 10^6.e^{-0.023 \times 20}$ [allow ecf of λ for this mark] **(1)**
Correct answer [9.5×10^5(Bq m^{-2})] **(1)**
[2040(Bq m^{-2}) scores 2/3]
OR
Work out number of half lives **(1)**
Use the power equation **(1)**
Correct answer **(1)** 3

Example of calculation:
$\lambda = \ln 2 / 30 = 0.023$ yr^{-1}
$R = 1.5 \times 10^6.e^{-0.023 \times 20}$ Bq m^{-2}
$R = 9.5 \times 10^5$ Bq m^{-2}

Assumption:
the only source in the ground is ^{137}Cs / no ^{137}Cs is washed out of**(1)** 1
soil / no clean-up operation / no further contamination / reference to weather not changing the amount

Scattered isotopes:

(^{131})I and ^{134} Cs **(1)**
For either isotope: many half lives have passed / half life short compared to time passed / short half life therefore **now** low emission **(1)** 2

Comment:
Even the isotopes with a thirty year half life are still highly radioactive [eg accept strontium hasn't had a half life yet] **(1)**
Plutonium will remain radioactive for thousands of years (as the half life is very large) [accept the alpha emitting isotopes for plutonium] [accept plutonium half lives much longer than 20 years] **(1)** 2

[11]

15. (a) Sources of background radiation

2 from:
Cosmic rays, rocks, soil, food, nuclear power/industry[buried waste as alternative], atmosphere, building material, medical uses, nuclear weapons testing (in the 60 s), Sun, radon gas 2

[Do not credit more than 1 example in each category e.g. coffee and Brazil nuts is 1 mark not 2]

(b) (i) Measurement of background count rate

- Use GM tube or stop watch/ratemeter/datalogger **(1)**
- All sources must be in their (lead) containers / placed away from the **(1)** experiment / place thick lead around tube
- Measure count over measured period of time **(1)** (and divide count by time)
- Repeat and average / measure the count for at least 5 minutes **(1)**
- Subtract background (count rate) from readings **(1)**

max 4

(ii) Why it might be unnecessary to measure background count rate

Count rate for the radioactive material is much greater than the background count rate. **(1)** 1
[Comparison required with count rate of radioactive material]

[7]

16. (a) (i) Stable ?

Will not: decay / disintegrate / be radioactive / emit radiation / emit **(1)** particles / break down 1
[Do not accept will not emit energy]

(ii) Complete equation

${}^{1}_{1}Y$ **(1)** 1

(iii) Identify particles

X = neutron **(1)**
Y = proton **(1)** 2

(b) (i) Decay Constant

Use of $\lambda = \frac{0.69}{t_{1/2}}$ i.e. $= \frac{0.69}{5568 \times 3.2 \times 10^{7}\,s}$ **(1)**

[Do not penalise incorrect time conversion]

Correct answer [3.87×10^{-12} (s^{-1})] to at least 2 sig fig. [No ue] **(1)** 2
[Bald answer scores 0]

(ii) Number of nuclei

Use of A = λN eg $\frac{16}{60}$ = (–) 4 × 10^{-12} N **(1)**

[Ecf their value of λ] [Do not penalise incorrect time conversion]

Answer in range 6.6 × 10^{10} to 7.0 × 10^{10} **(1)** 2

[8]

17. (a) (i) Complete equation

Correct identification of $^{4}_{2}$ for α **(1)**

Correct substitution **(1)** 2

$^{27}_{13}$ OR correct values which balance the candidate's equation

(ii) Completion of 2nd equation

$^{0}_{1}$ **(1)**

Correct identification of positron / positive (+ ve) electron / β^+ / **(1)** 2
antielectron

[If incorrectly given $^{0}_{-1}$ allow electron / β^- ie 1 mark]
[Correct spelling only]

(b) Half-life

Average **(1)**

Time taken for the activity/intensity/count rate to drop by half
OR time taken for half the atoms/nuclei to decay **(1)**

[NOT mass, count, particles, radioisotope, sample]

Isotope

Same: proton number / atomic number **(1)**
[Not same chemical properties]

Different: neutron number / nucleon number / mass number **(1)** Max 3

[Not different physical properties/density]

(c) <u>γ-ray emission</u> 1

EITHER	OR
(The loss of a helium nucleus/electron has left the remaining) nucleus in an excited state/with a surplus of energy	The nucleus emits its surplus energy (in the form of a quantum of γ-radiation) **(1)**

[8]

18. <u>Why gamma radiation used</u>

γ is the <u>most</u>/<u>more</u> penetrating **(1)** 1

(OR α/β **<u>less</u>** penetrating)

<u>Factors controlling amount of radiation</u>

Any 2 from:

- Strength/type of radiation source/half-life/age of source
- speed of conveyor belt/exposure time
- shape/size of food packages/surface area
- distance from radiation source **(1) (1)** Max 2

<u>Suitable material for wall</u>

Concrete/lead **(1)**

<u>Suitable thickness</u>

30 cm – 1 m/1 – 10 cm **(1)** **2**
[thickness mark dependant on named material]

<u>Source of natural radiation</u>

Rocks, soil, cosmic rays, named radioactive element, sun, space, air **(1)** 1

[6]

19. <u>Age of part of the stalagmite</u>

$\lambda = ln2/t_{1/2} = 1.2 \times 10^{-4}$ years^{-1} (= 3.8×10^{-12} s^{-1}) **(1)**

Use of $N = N_0e^{-\lambda t}$ **(1)**
$1 = 256\ e^{-1.2 \times 10-4t}$
[allow 255 instead of 1 for this mark but do not carry forward]

t = 46 000 years (= 1.45×10^{12} s) **(1)** 3

[OR recognise 1/256 **(1)**
8 half-lives **(1)**
45 800 years **(1)**]

Carbon-14 concentration

Carbon-14 measurement would be greater **(1)** 1

Validity of radio-carbon dating

3 points, e.g.

- not valid
- twice original concentration gives greater proportion measured now
- object seems younger than it actually is
- older parts could have more carbon-14 than younger parts
- technique relies on constant levels, therefore unreliable
- mixture of old and young carbon-14 in 1 stalagmite makes dating impossible **(1) (1) (1)** 3

[7]

+ü**20.** Velocity of jumper

$\omega = 2\pi/T = 2\pi/5.0$ s (= 1.26 s^{-1}) **(1)**

$\upsilon_{max} = A\omega$

= 4.0 m × 2π/5.0 s

=5.0(3) (m s^{-1}) **(1)** 2

Why tension in rope and jumper's weight must be balanced

When υ is maximum, acceleration = 0 **(1)**

so net force = 0 **(1)** 2

[OR: If forces not in equilibrium, he would accelerate/decel. **(1)**
So velocity cannot be maximum **(1)**]

Calculation of force constant for rope

Use of $T = 2\pi\sqrt{m/k}$ **(1)**

Hence $k = 4\pi^2 m/T^2 = 4\pi^2 \times 70$ kg/(5.0 s)^2

= 109 – 111 N m^{-1} [kg s^{-2}] **(1)** 2

Verification that rope is never slack during oscillations

$F = mg$ = 70 kg × 9.81 N kg^{-1} = 687 N **(1)**

At centre of oscillation, when forces in equilibrium,

$x = F/k$

= 687 N/110 N m^{-1} (allow e.c.f. from previous part) **(1)**

= 6.2 m which is larger than amplitude **(1)** 3

OR

Calculation of a_{max} (= $-\omega^2 A$) [6.32 m s^{-2}] **(1)**

Comparison with g 9.81 m s^{-1} **(1)**

Deduction **(1)**

Likewise for forces approach.

Motion of jumper

Any 1 from:

- motion is damped shm
- so amplitude decreases
- but period stays (approximately) the same **(1)** 1

[10]

21. Decay constant

λ = 0.69/432 (yr^{-1}) **(1)**

$\lambda = 5.1 \times 10^{-11}$ (s^{-1}) [At least 2 significant figures] **(1)** 2

Number of nuclei

3.0×10^{13} **(1)** 1

Activity calculation

Use of $A = \lambda N$ **(1)**

$A = 1.5 \times 10^3$ Bq / s^{-1} [ecf] **(1)** 2

Explanation

Range few cm in air / short range **(1)**

Alpha would produce enough ions (to cross gap) OR ionises densely/strongly/highly **(1)** 2

Features of americium sample

Half–life long enough to emit over a few years **(1)**

Count well above background **(1)**

Suitable as safe as range very low / shielded **(1)** 3

[10]

22. (a) Explanation of binding energy

Energy required to separate a nucleus **(1)**

into nucleons **(1)**

What this tells about an iron nucleus

Iron is the most stable nucleus **(1)** 3

(b) Nuclear equation for decay

$^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}\beta / {}^{0}_{-1}e + \overline{\nu}$

Symbols [C → N + β] **(1)**

Numbers [14, 6, 14, 7, 0, –1] **(1)**

Antineutrino / $\overline{\nu} / \overline{\nu}_e$ **(1)** 3

Estimate of age of a fossil

3 half–lives **(1)**

giving 17 000 years to 18 000 years **(1)** 2

23. Why γ rays are dangerous

For example:

Penetrates (skin) **(1)**

Can cause ionisation / cell damage / mutation **(1)** 2

[not kill cells]

Material for shielding

Lead **(1)**

Several centimetres (0.5 → 5 cm) **(1)** 2

Why α radiation not used

Not (sufficiently) penetrating (not absorbed by luggage) **(1)** 1

Increased background radiation

Exposed to more cosmic radiation **(1)**

Less atmosphere above them for shielding **(1)** 2

[7]

24. Isotopes

same	different
Number of protons	Number of neutrons
Atomic number	Neutron number
Element	Nucleon number
Proton number	Atomic mass
	Mass number

(1) 1

Polonium decay

Po at (84, 210) with label **(1)**

2 steps west **(1)**

4 steps south **(1)** 3

Experimental check

Use of GM tube **(1)**

Inserting sheet of paper/aluminium foil/very thin aluminium/a few cm of air stops the count **(1)**

Measure background, and look for count rate dropping to background **(1)** 3

NB Award points 2 and 3 for correct converse argument.

[7]

25. Meanings ot terms

Range: distance travelled (before being stopped) **(1)**

Ionises: removes electron(s) from atoms **(1)** 2

Explanation

More strongly ionising means shorter range **(1)**

ionising means energy lost **(1)** 2

Mass

Use of $m = \rho V$ **(1)**

8.1 kg **(1)** 2

T'hickness of lead sheet

Use of 8.1 kg/ρ OR t proportional to 1/ρ **(1)**

0.7 mm **(1)** 2

[8]

26. Emission - written above arrows

α β^- β^- α α
All five correct [Allow e^-, $^4He^{2+}$] **(1) (1)** 2
[For each error –1]
[α β β α α gets 1/2]
Number of alpha particles emitted
Five **(1)** 1

[3]

27. Nuclear radiation which is around us

Background **(1)** 1

Source of radiation

e.g. Sun / rock (eg granite) / cosmic rays [not space] / **nuclear** power stations **(1)** 1

Why exposure greater today

Nuclear power stations/nuclear bomb tests/X–rays/
Radon from building materials **(1)** 1

Beta radiation

(i) Any two from:

- γ more difficult to shield
- β lower range (than γ)
- β more ionising (than γ) **(1) (1)**

(ii) α stopped by a few cm of air or has a short range/much lower range (than β) / β radiation has a long range **(1)** 3

Why gamma radiation is suitable

Any two from:

- γ will pass through (metal of) wing / α and β cannot pass through the wing
- but passes more easily through cracks
- hence crack shows as darker mark on photo or increased count on detector **(1) (1)** 2

[8]

28. Plutonium-238

238 protons + neutrons [OR nucleons] in the (nucleus of the) atom **(1)** 1

Why plutonium source caused concern

If accident at launch, radioactive Pu would be spread around Earth **(1)** 1

Activity of plutonium source

$\lambda = \ln 2/88 \times 3.16 \times 10^7$ s $= 2.5 \times 10^{-10}$ (s^{-1}) **(1)**

Use of $dN/dt = -\lambda N$ **(1)**

$= 2.5 \times 10^{-10}\ s^{-1} \times 7.2 \times 10^{25} = 1.8 \times 10^{16}$ (Bq) **(1)** 3

Power delivered by plutonium

Use of power = activity × energy per decay **(1)**

$= 1.79 \times 10^{16}$ Bq $\times 5.6 \times 10^6 \times 1.6 \times 10^{-19}$ s

[conversion of MeV to J] **(1)**

$= 1.6 \times 10^4$ (W) **(1)** 3

[2×10^{16} Bq gives 1.79×10^4 (W)]

Whether power can be relied upon

Large number of nuclei present, so decay rate (almost) constant **(1)** 1

Percentage of power still available after 10 years

Percentage $= N/N_0 \times 100 = 100\ e^{-\lambda t}$ **(1)**

$= 100\ e^{-10 \times \ln 2/88} = 92\%$ **(1)** 2

[After 10 y, $N = N_0\ e^{-\lambda t} = 7.2 \times 10^{25} \times 0.92 = 6.65 \times 10^{25}$ **(1)**]

Why plutonium was chosen for Cassini mission

Examples:

- long (enough) half–life for duration of mission
- Power constant / no orientation problems compared with solar
- α-emitting, so energy from particles easily transferred
- availability **(1)** 1

[12]

29. Graph

Sensible scale + point (0, 192) plotted **(1)**

Rest of points [–1 mark for each misplot] **(1) (1)** 3

[(1,96); (2, 48); (4, 12)]

[Accept bar chart]

Random process

Cannot predict which nuclei will decay/when a particular nucleus will decay **(1)** 1

Model

Cannot predict which children will flip a head/which coins will be heads/when a particular coin /child will flip a head **(1)** 1

Half-life

Time taken for activity/count rate to drop by half/time taken for half the atoms/nuclei to decay **(1)** 1

How model illustrates half-life

Yes, if children were told to flip coin at regular time interval
OR
Yes, because about half of the children flipped a head each time
OR
No, because time is not part of the experiment **(1)** 1

[7]

30. Revision Notes: Radiation

One suitable source, e.g. cosmic radiation, rocks, soil, medical equipment, power stations. **(1)** 1

Nuclear radiation properties

	Alpha	Beta	Gamma
Ionising ability	(Very) strong	Medium	Weak
Penetration power (stopped by)	Thin paper or 3-10 cm air	Few mm aluminium or few × 10 cm air	Many cm lead of m of concrete

1

Correct materials for both alpha and beta **(1)**

Correct thickness for one correct material **(1)** 3

[4]

31. Oscillations

Correct ticks/cross **(1)**
Reasons **(1) (1) (1)** 4

Oscillations	SHM ✓ ✗	Reason
Mass on end of spring	✓	Force ∝ displacement [OR acceleration ∝ displacement] OR Force always towards the equilibrium position
Child jumping up and down	✗	Force constant when child in the air OR Period/frequency not independent of amplitute
Vibrating guitar string	✓	Force ∝ displacement [OR acceleration ∝ displace-ment] OR Frequency not dependent on amplitute

[4]

32. Nuclear equation

$^{115}_{49}\text{In} \rightarrow ^{115}_{50}\text{Sn} + ^{0}_{-1}\text{e} / ^{0}_{-1}\beta$

Correct symbol and numbers for tin OR beta	1
Correct symbols and numbers for the other two	1
Decay constant	
Use of $\lambda = 0.69/t_{1/2}$	1
1.57×10^{-15} y^{-1} OR 4.99×10^{-23} s^{-1}	1
Activity of source and comparison with normal background count rate	
Use of $A = \lambda N$.	1
0.11/0.12 (Bq)	1
Lower (than background) [Allow ecf- assume background = 0.3 to 0.5]	1

[7]

33. Radiation tests

Alpha:	
Test 2 or 2 and 1	1
Count drops when alphas have been stopped by the air / alphas have a definite range / (only) alpha have a short range (in air)	1
Beta:	
Test 3/3 and 1 , because 1 mm aluminium stops (some) beta/does not stop any gamma rays	1
Gamma:	
Test 4 or 4 and 1, because 5 mm aluminium will stop all the betas, (so there must be gamma too)/gamma can penetrate 5 mm of aluminium	1

[4]

34. Equation

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

14/7 and 1/0	1
1/1 [no e.c.f.]	1
Hence X is H atom/H nucleus/proton/H/hydrogen	1
Estimation of age	
Down to 1.9 cpm needs 3 half-lives	1
3×5730	1
17 000/17244 years/5.4×10^{11}s	1

Suggested problem in measuring

Background count mentioned/randomness significant 1

[OR need larger mass than one gram]

[7]

35. Number of neutrons

8 **(1)**

Decay constant

Use of $\lambda = 0.69/t_{1/2}$ **(1)**

$\lambda = 1.2 \times 10^{-4}$ yr^{-1} OR 3.9×10^{-12} s^{-1} **(1)** 3

Number of nuclei

3.0×10^{14} **(1)**

Calculation of activity

Their N × their λ **(1)**

= 1170 Bq [No e.c.f. if **no** conversion to seconds] **(1)** 3

Nuclear equation

${}^{14}_{6}\text{C} \rightarrow {}^{14}_{7}\text{N} + {}^{0}_{-1}e$ **(1) (1)** 2

[8]

[1 mark for ${}^{14}_{7}\text{N}$, 1 mark for ${}^{0}_{-1}e$ as ${}^{0}_{-1}\beta$]
[Must be on correct side of arrow]

36. Calculation of age of the Moon

Any six from:

$\lambda = \ln 2$ / half-life **(1)**

$= \ln 2 / 1.3 \times 10^{9}$ y

5.3×10^{-10} y^{-1} **(1)**

Original mass of $^{40}K = 0.10 + 0.840 = 94\ \mu g$ **(1)**

Use of $N = N_0 e^{-\lambda t}$ **(1)**

So $0.10 = 0.94\ e^{-\lambda t}$ **(1)**

So $\ln(0.10/0.94) = -\lambda t$ **(1)**

So $t = 4.2 \times 109$ y **(1)**

[A valid assumption may be given a mark]

[Max 6]

37. Precautions
Measure background radiation //shield apparatus **(1)**
Subtract it off/ because it may vary//to eliminate background **(1)**
Repeat the count and average **(1)**
Because count (or emission) is random/varying **(1)**
Source the same distance from GM on both occasions **(1)**
Because count rate varies with distance **(1)** Max 3
[NB Marks must come from any TWO precautions.]

Ratio
0.88 or 1.1 [min. 2 sfi [not %] **(1)** 1

Count for year 3
11 994 **(1)** 1

Graph
Suitable axes and scales [don't award if factors 3, 7 used] [not Bq] **(1)**
Correct plotting of points **(1)**
Use of curve and halving count rate **(1)**
5.3 to 5.4 yr **(1)** 4

[9]

38. Name of nuclei
Isotopes [not radioisotopes] **(1)**

Nuclear equation
$^{111}_{50}\text{Sn} \rightarrow {}^{0}_{1}\text{e}\,(\text{or}\,\beta) + {}^{111}_{49}\text{In}$
Electron numbers correct anywhere **(1)**
Correctly balanced **(1)**

Densest material
Sn-115 **(1)**

[4]

39. Warm river

How radioactive nuclei heat,

e.g. by decay/ionising/nuclear radiation 1

α, β and γ radiation

α helium nucleus [or equivalent] **(1)**

β (fast) electron **(1)**

γ electromagnetic wave **(1)**

[Accept an answer that fully differentiates between the types of radiation by describing their properties] 3

Most hazardous nuclei

α emitting **(1)**

When ingested, α particles damage body cells

[e.c.f. from previous β or γ linked to penetration & damage] **(1)** 2

Source of radioactivity

e.g. rocks, Sun, cosmic radiation 1

[7]

40. Compositions of nuclei:
Different number of neutrons **(1)**
Same number of protons / proton no. **(1)**

Physical property:
Boiling point/melting point/density/ [not mass; heavier; RAM] **(1)** 3

Nuclear Equation:

$\binom{3}{1}\mathrm{H}$ **(1)**

$\binom{3}{2}\mathrm{He}$ **(1)**

$\binom{0}{-1}\beta$ **(1)** 3

Experiment:
GM tube [allow ionisation chamber, cloud chamber] **(1)**

How to check no alpha:
Source close/next to/near/up to 5 cm to GM or ionisation /cloud chamber, insert paper, no change in 'count rate'

OR

Source close to GM, move away, no sudden drop in count rate **(1)**

How to check no gamma:
Insert a few mm aluminium, count rate reduced to zero

OR

Apply E or B field, GM tube fixed, count rate to zero **(1)**

Correcting/Allowing for background (i.e. measure it, and look for count reducing to background in "no gamma" test) **(1)** 4

[10]

41. Half-life:
Use of $t_{1/2}\ \lambda = 0.69$ **(1)**
13 **(1)**

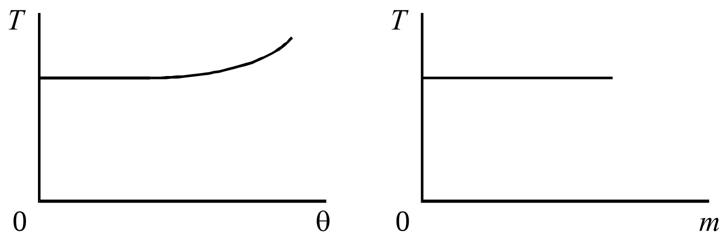
Initial number of nuclei:
Use of $A = \lambda N$ (ignore wrong time units) **(1)**
1.0×10^{15} **(1)** 4

Graph:
Horizontal line from same initial point **(1)**
[max drop 1 small square]

Initial activity marked as 6.4×10^8 Bq or equivalent scale **(1)**
Their half-life marked where $A = 3.2 \times 10^8$ Bq, or equivalent scale **(1)** 3

[7]

42. Graphs:



(2) 2

Description:
Time for a number of cycles ÷ by no. of cycles **(1)**
[accept swings]
Count from centre of swing/repeat timing and average/keep amplitude small **(1)**
Repeat for different lengths AND plot Graph of T v $\sqrt{l}$ **(1)**
[allow for ratio method]
should be straight line through origin [consequent] **(1)**
[allow for ratio method] 4

Calculation (based on graph):
Attempt to find gradient **(1)**
Rate of change = 0.103 –0.106 $s^2\ m^{-1}$ **(1)**

Rate of change of *l* plus comment on answer:
9.6 $m\ s^{-2}$ [1/their value above] [no ue] [ecf] **(1)**
close to/roughly/approx. acceleration of free fall/*g* **(1)**
[only if range 8.8 to 10.8 $m\ s^{-2}$] 4

[10]

43. Nuclear equation:

$^{32}_{15}P \rightarrow ^{32}_{16}S + \beta^- \left| ^{0}_{-1}\beta \right| ^{0}_{-1}e \right|$ e^- [Ignore + γ + υ] **(1)**

1

Description:

Take background count **(1)**

Take count close to source, then insert paper/card and count **(1)**

Little/no change **(1)**

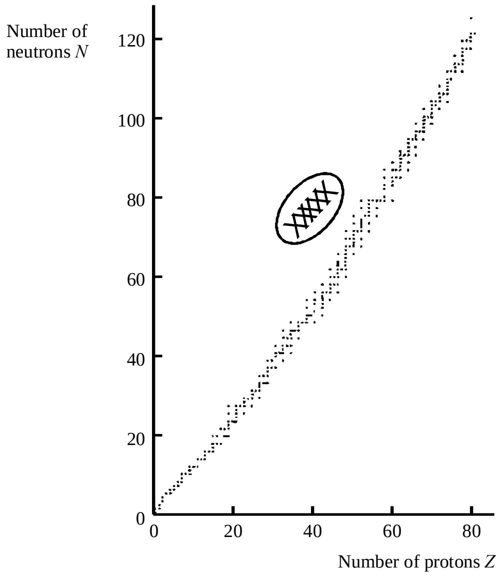
[OR absorption in air: Take close reading and move counter back; no sudden reduction **(1)(1)**]

Insert sheet aluminium and count **(1)**

Down to background, or zero **(1)**

Max 4

Diagram: Any region above dots [show **(1)** or **(X)**] **(1)**
1



Explanation:

1 β^- decay involves a neutron $\rightarrow$ a proton Any two from: **(1)**

Any two from:

2. on the diagram this means $\downarrow^{-1}$ ($^{+1}$ / diagonal movement

3. so nuclide moves towards dotted line

4. decay means greater stability **(1)(1)**

[β^- in wrong region, (1) and (4) only available.

Decay towards drawn $N = Z$ line 1 and 2 only available]

[9]

44. Sources of background radiation:

Radioactive rocks/radon gas/cosmic rays or solar wind **(1)**

Fall out/leaks from nuclear installations
named materials, e.g. uranium/granite/^{14}C **(1)** 2

Nuclear equation:

$^{22}_{11}Na \rightarrow\ ^{22}_{10}Ne +\ ^{0}_{+1}\mathrm{e}$ [Accept β]

22 and 0 **(1)**
10 and +1 OR 10 and 1 **(1)**
20 – 26 Na [NOT ^{22}Na] [Must have correct proton number, if given] **(1)** 3

Decay constant of sodium–22 in s^{-1}:

λ =0.69/2.6 [Ignore conversion to seconds] [Not 0.69/1.3] **(1)**

$\lambda = 8.4 \times 10^{-9}$ [No unit, no e.c.f.] **(1)**

Number of nuclei:

$2.5 = 8.4 \times 10^{-9}$ N **(1)**

$N = 3.0 \times 10^{8}$ **(1)** 4

Whether salt is heavily contaminated:

(No.) This is a small number (compared to no. of atoms in a spoonful of salt)

OR

Rate < background **(1)** 1

[10]

45. Uranium correctly marked at (92, 142) **(1)**

Beta decay: SE at 45° [One box] into the uranium **(1)**

Alpha decay: Proton number down 2 **(1)**

Neutron number down 2 **(1)**

[NB No arrows needed, but lines must be labelled appropriately; lines not essential if clear]

[4]

46. *N*–*Z* grid

Sr at 38, 52 **(1)**

Y at 39, 51 [e.c.f. Sr incorrect $\rightarrow$ 1 diagonal move] **(1)** 2

Rb at 37, 45 **(1)**

Decays by β^+ emission/positron/α **(1)** 2

[4]

47. How to determine background radiation level in laboratory:

Source not present/source well away from GM tube [> 1 m] **(1)**

Determine - count over a specific period of time
> 1 min OR repeats **(1)** 2

How student could confirm that sample was a pure beta emitter:

To demonstrate no γ:

A1 between tube and source: reading $\rightarrow$ 0 or background **(1)**

No γ / γ not stopped by Al **(1)**

To demonstrate no α:

GM moved from very close (or $\approx$ 1 cm) to source
to $\approx$ 10 cm: count rate does not drop (or no sudden drop) **(1)**

No α / α stopped by a few cm air **(1)**

Clarity: Only available if at least 2 of above 4 marks
awarded. Use of bullet points acceptable. **(1)** 5

[7]

48. Half-life of radionuclide:
One value for half-life: 33 $\rightarrow$ 36 s
Repeat and average/evidence of two values (u.e.) 2

Decay constant:
ln2 ÷ *their* value for $t_{1/2}$ calculated correctly
= (0.02) s^{-1} (u.e.) 1

Rate of decay:

Tangent drawn at $N = 3.0 \times 10^{20}$
Attempt to find gradient, ignore "–" sign
= 5.5 $\rightarrow$ 6×10^{18}
[*or* Use of $N = N_{oe}^{-\lambda t}$, calculate λ, *or* other graphical means]

[NB 6.25×10^{18} = 0/3 as use of coordinates] 3

Decay constant:

Substitute in $dN/dt = -\lambda N$
e.g. $6 \times 10^{18} = (-)\lambda \times \underline{3 \times 10^{20}}$ [*their* above]
= (0.02) [*their* λ correctly calculated] 2

Methods: 1

Either value chosen with a valid reason

e.g. 1st because can take several and average
1st because difficult to draw tangent

[9]

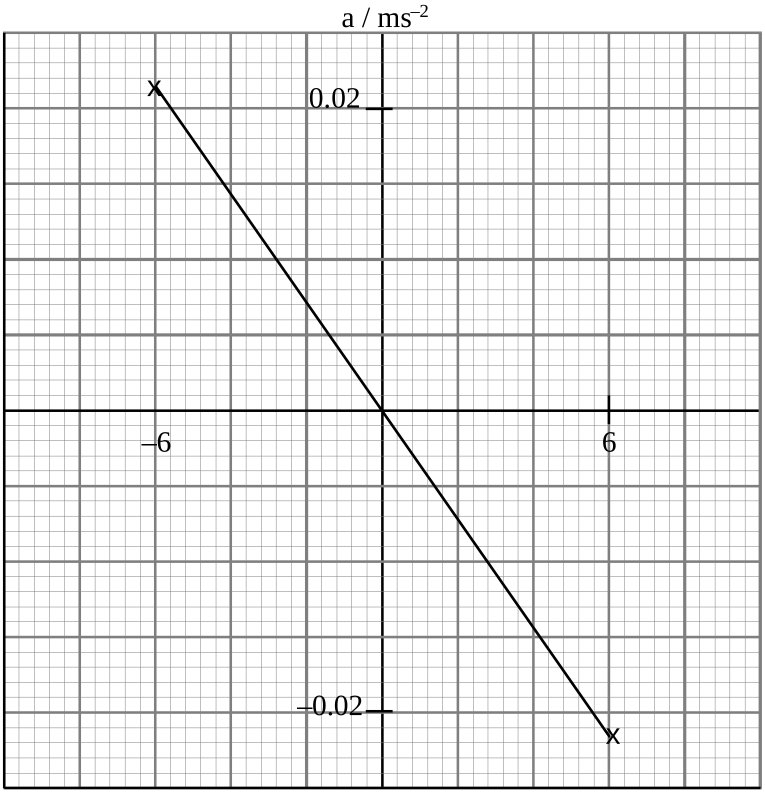
49. Maximum acceleration of mass:

$a = (-)\ \omega^2 x$ with $x = 6.0$ mm used *or* $a = (-)(2\pi f)^2\ x$

$\omega = \dfrac{2\pi}{3.2}$ *or* $f = \dfrac{2\pi}{3.2}$

$= 23\ \text{mm s}^{-2}$ [u.e.] 3

Graph:



Straight line
Negative gradient
4 quadrants: line through 0,0
Line stops at 6, 0.023 [e.c.f. *x, a*] 4

Reason why mass may not oscillated with simple harmonic motion:
F not proportional to *x or a* not proportional to *x*
Spring past elastic limit: *K* not constant: spring may swing as well as bounce.
Other possibilities, but not air resistance, energy losses 2

[9]

50. (i) Reference to (individual) nuclei/atoms/particles
Each has a chance of decay/cannot predict which/when
will decay 2

(ii) Use of $\lambda t_{½} = \ln 2$
$\rightarrow \lambda = \ln 2 \div 600$ s = 1.16/1.2 × 10^{-3} s^{-1}
$\therefore A = (1.16 \times 10^{-3}\ s^{-1})\ (2.5 \times 10^{5})$ [Ignore minus sign]
= 288/290 Bq/s^{-1} [c.a.o.] [Not Hz] [17 300 min^{-1}]

(iii) ${}^{13}_{7}N \rightarrow {}^{0}_{1}e\,/\,{}^{0}_{1}\beta + {}^{13}_{6}C\,/\,X\ (+\ \nu_e)$ [N/O/C/X] [e.c.f. β^-]
[β^+ on left, max 1/2] 5

[7]

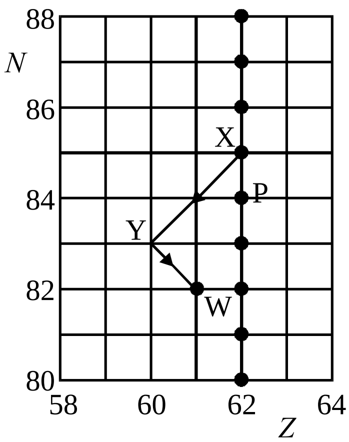
51. Type of radioactive decay
α-decay

Nuclear equation for decay

$${}^{147}_{62}\times{}^{143}_{60}\mathrm{Y} + {}^{4}_{2}\alpha\,/\,{}^{4}_{2}\mathrm{HE}$$

[1 mark for letters, 1 mark for numbers]

Addition of arrow to diagram



Point P on diagram

[5]

52. Design of experiment to find what types of radiation are emitted:

Soil in container with opening facing detector

Take background count /or shield apparatus

With detector close to soil, insert paper

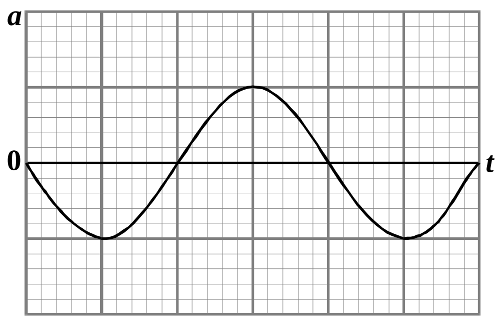
or take close reading then at, ≈ + 5 cm; count rate reduced so α present

Insert aluminium foil: further reduction $\therefore \beta$ present

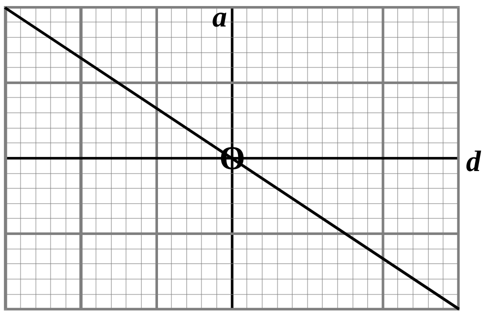
Insert lead sheet: count rate still above background *or* count rate reduced to zero, $\therefore \Upsilon$ present.
or, if no count after aluminium foil, no Υ
or, if count rate above background with *thick* aluminium, then Υ present

[5]

53. Sketch of two graphs:



Sinusoidal
Negative start



Linear through 0,0
Negative gradient 4

Amplitude of tide = 3.1 m

Next mid-tide at 12.00 (noon)

Next low tide at 15.00 (3 pm) 3

Calculation of time at which falling water levels reaches ring R:

$x = x_0 \sin\left(\frac{2\pi t}{12}\right)$ [Allow cosine]

$1.9 \text{ m} = 3.1 \text{ m} \sin\left(\frac{2\pi t}{12\text{h}}\right)$

[Error carried forward for their amplitude above; not 1.2 ml

t = 1.26 h *or t* = 4.25 h if cosine used

Time at R = 12.00 h + 1.26 h = 13.26 h (1.16 pm) 4

[11]