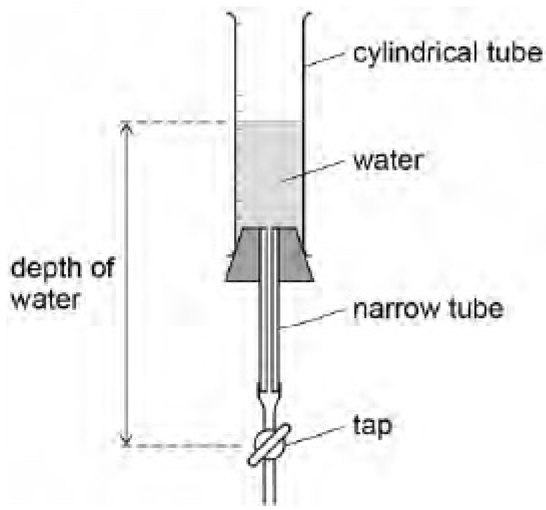
1 **Figure 1** shows how radioactive decay of one nuclide can be modelled by draining water through a tap from a cylindrical tube.

Figure 1

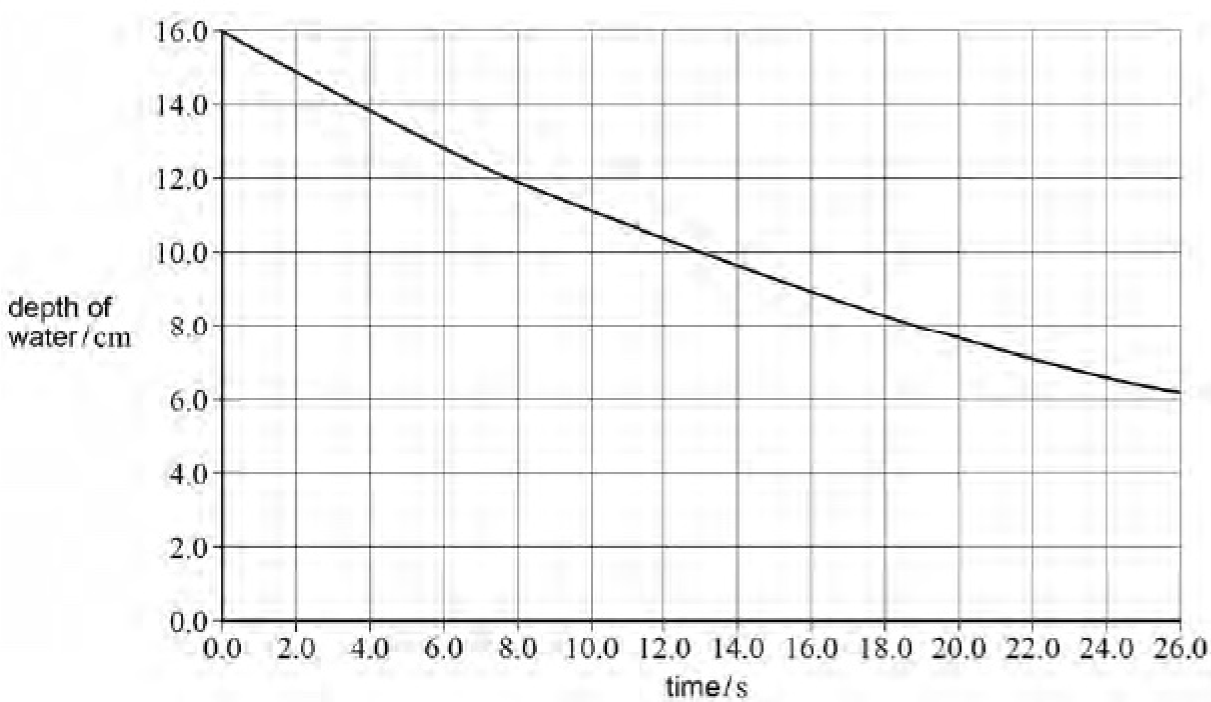


The water flow-rate is proportional to the pressure of the water. The pressure of the water is proportional to the depth of the water. Therefore the rate at which the depth decreases is proportional to the depth of the water.

Before the tap is opened the depth is 16.0 cm

The tap is opened and the depth is measured at regular intervals. These data are plotted on the graph in **Figure 2**.

Figure 2



(a) Determine the predicted depth of water when the time is 57 s

$t_{1/2} = 19$ sec. so 3 half lives $16 \Rightarrow 8 \Rightarrow 4 - 2$

depth = 2 cm

(1)

(b) Suggest how the apparatus in **Figure 1** may be changed to represent a radioactive sample of the same nuclide with a greater number of nuclei.

deeper

(1)

(c) Suggest how the apparatus in **Figure 1** may be changed to represent a radioactive sample of a nuclide with a smaller decay constant.

λ : decay/sec so we need less water/sec so partially close tap

(1)

(d) The age of the Moon has been estimated from rock samples containing rubidium (Rb) and strontium (Sr), brought back from Moon landings.

$^{87}_{37}Rb$ decays to $^{87}_{38}Sr$ with a radioactive decay constant of 1.42×10^{-11} year^{-1}

Calculate, in years, the half-life of $^{87}_{37}Rb$

$t_{1/2} = \frac{\ln 2}{\lambda} = 4.88 \times 10^{10}$

half-life = ____________________ years

(1)

(e) A sample of Moon rock contains 1.23 mg of $^{87}_{37}\mathrm{Rb}$.

Calculate the mass, in g, of $^{87}_{37}\mathrm{Rb}$ that the rock sample contained when it was formed 4.47×10^9 years ago.

Give your answer to an appropriate number of significant figures.

$n = n_0 e^{-\lambda t}$ but $n \propto m$ so we can say

$m = m_0 e^{-\lambda t}$

λt has no units so as long as λ & t are in same unit then it's ok.

$\lambda t = 1.42 \times 10^{-11} \times 4.47 \times 10^9$

$= 0.063$

$1.23\,mg = M_0 e^{-0.063}$

$\Rightarrow M_0 = 1.31\,mg$

mass = 1.3×10^{-3} g

(3)

(f) Calculate the activity of a sample of $^{87}_{37}\mathrm{Rb}$ of mass 1.23 mg

Give an appropriate unit for your answer.

$A = \lambda n$

sec.

$\lambda = 1.42 \times 10^{-11} / yr$

$\lambda = \frac{1.42 \times 10^{-11}}{365 \times 24 \times 60^2} = 4.5 \times 10^{-19}$

$n = \frac{1.23\,mg}{87} \times 6.02 \times 10^{23}$

$n = 8.51 \times 10^{18}$

$\therefore A$

activity = 3.8 unit s^{-1}

(3)

(Total 10 marks)

2 The radius of a uranium ${}^{238}_{92}\text{U}$ nucleus is 7.75 × 10^{-15} m

What is the radius of a ${}^{12}_{6}\text{C}$ nucleus?

$R = R_0 A^{1/3}$

A	1.10 × 10^{-18} m	⬭
B	3.91 × 10^{-16} m	⬭
C	2.86 × 10^{-15} m	⬭
D	3.12 × 10^{-15} m	⬭

$\frac{R}{A^{1/3}} = R_0 \Rightarrow R_0 = 1.25 \times 10^{-15}$

$R = R_0 A^{1/3}$ values for ${}^{12}C$

(Total 1 mark)

3 (a) In a radioactivity experiment, background radiation is taken into account when taking corrected count rate readings in a laboratory. One source of background radiation is the rocks on which the laboratory is built. Give **two** other sources of background radiation.

source 1 Sun

source 2 fall out from explosions/power stations

(1)

(b) A γ ray detector with a cross-sectional area of 1.5 × 10^{-3} m^2 when facing the source is placed 0.18 m from the source.
A corrected count rate of 0.62 counts s^{-1} is recorded.

(i) Assume the source emits γ rays uniformly in all directions.
Show that the ratio

$$\frac{\text{number of } \gamma \text{ photons incident on detector}}{\text{number of } \gamma \text{ photons produced by source}}$$

is about 4 × 10^{-3}.

Source emission goes out in a sphere $= 4\pi r^2 = 0.407\ m^2$

detector covers $\frac{1.5 \times 10^{-3}}{0.407} = 3.7 \times 10^{-3} \approx 4 \times 10^{-3}$

(2)

(ii) The γ ray detector detects 1 in 400 of the γ photons incident on the facing surface of the detector.
Calculate the activity of the source. State an appropriate unit.

0·62 counts/s so no of γ = 400 × 0·62
= 248/s

so A = 248 × $\frac{1}{3.7 \times 10^{-3}}$ =

answer = 6·7×10⁴ unit Bq or s^{-1}

(3)

(c) Calculate the corrected count rate when the detector is moved 0.10 m further from the source.

0·62/s at 0·18 m new dist = 0·28

$c \propto \frac{1}{r^2}$ r changed by a factor $\frac{0.28}{0.18}$ = 1·56

∴ c changes by $\frac{1}{(1.56)^2}$ = 0·41

so 0·62 × 0·41 answer = 0·26 counts s^{-1}

(3)

(Total 9 marks)

4 (a) Calculate the binding energy, in MeV, of a nucleus of ${}^{59}_{27}\mathrm{Co}$.

nuclear mass of ${}^{59}_{27}\mathrm{Co}$ = 58.93320 u

mass should be $\underbrace{27 m_p + (\overset{32}{\cancel{59-27}}) m_n}_{\text{use u}} = 59.474\,u$

$\therefore \Delta m = 59.474 - 58.9332 = 0.5408\,u$

$E = 0.5408 \times 931.5\,\text{MeV}$

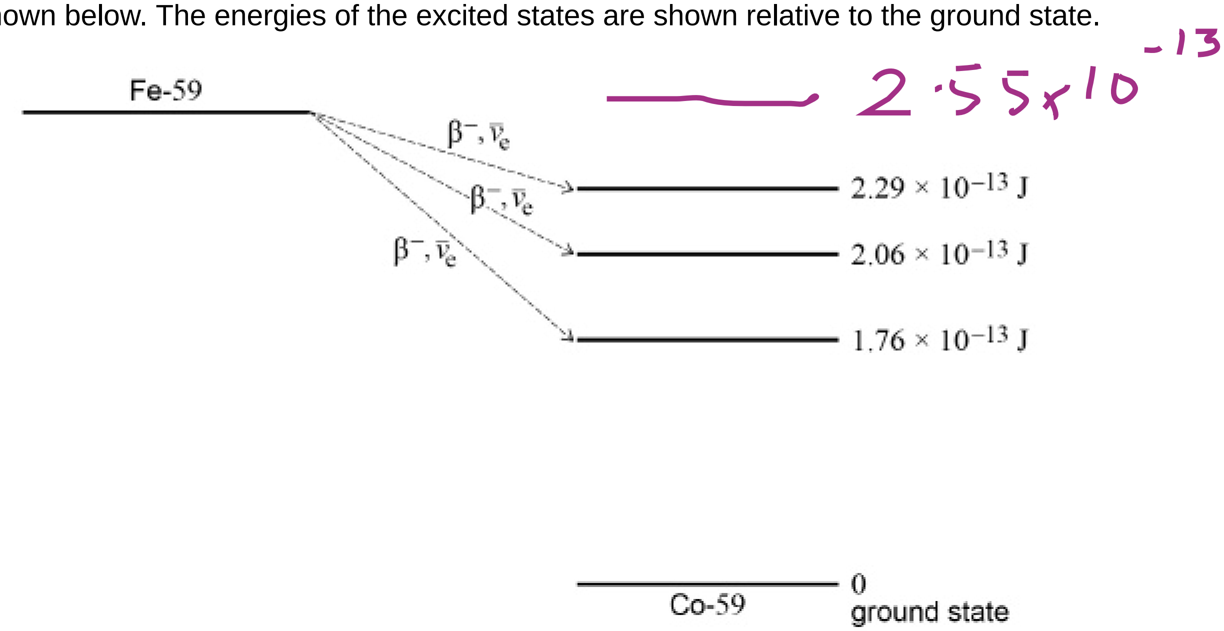
binding energy = 503.8 MeV

(3)

(b) A nucleus of iron Fe-59 decays into a stable nucleus of cobalt Co-59. It decays by β^- emission followed by the emission of γ-radiation as the Co-59 nucleus de-excites into its ground state.

The total energy released when the Fe-59 nucleus decays is 2.52×10^{-13} J.

The Fe-59 nucleus can decay to one of three excited states of the cobalt-59 nucleus as shown below. The energies of the excited states are shown relative to the ground state.



Calculate the maximum possible kinetic energy, in MeV, of the β^- particle emitted when the Fe-59 nucleus decays into an excited state that has energy above the ground state.

$2.52 \times 10^{-13} - 1.76 \times 10^{-13}$ J

0.76×10^{-13} J

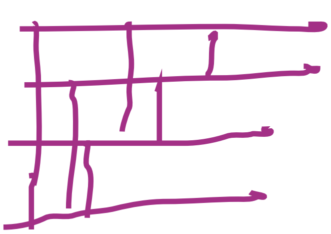
$= \dfrac{0.76 \times 10^{-13}}{1.6 \times 10^{-19}}$

maximum kinetic energy = 0.48 MeV

(2)

(c) Following the production of excited states of $^{59}_{27}Co$, γ-radiation of discrete wavelengths is emitted.

State the maximum number of discrete wavelengths that could be emitted.



maximum number = 6

(1)

(d) Calculate the longest wavelength of the emitted γ-radiation.

$c = f\lambda$

$E = hf = E = \frac{hc}{\lambda} \Rightarrow \lambda = \frac{hc}{E} =$ so smallest E

smallest $E = 0.23 \times 10^{-13}$ J

Longest wavelength = 8.6×10^{-12} m

(3)

(Total 9 marks)

5 Nobelium-259 has a half-life of 3500 s.

What is the decay constant of nobelium-259?

$\frac{\ln 2}{T_{\frac{1}{2}}} = 1.98 \times 10^{-4}$

A	8.7×10^{-5} s^{-1}	⬭
B	2.0×10^{-4} s^{-1}	⬭
C	1.7×10^{-2} s^{-1}	⬭
D	1.2×10^{-2} s^{-1}	⬭

(Total 1 mark)

6 After 64 days the activity of a radioactive nuclide has fallen to one sixteenth of its original value. The half-life of the radioactive nuclide is

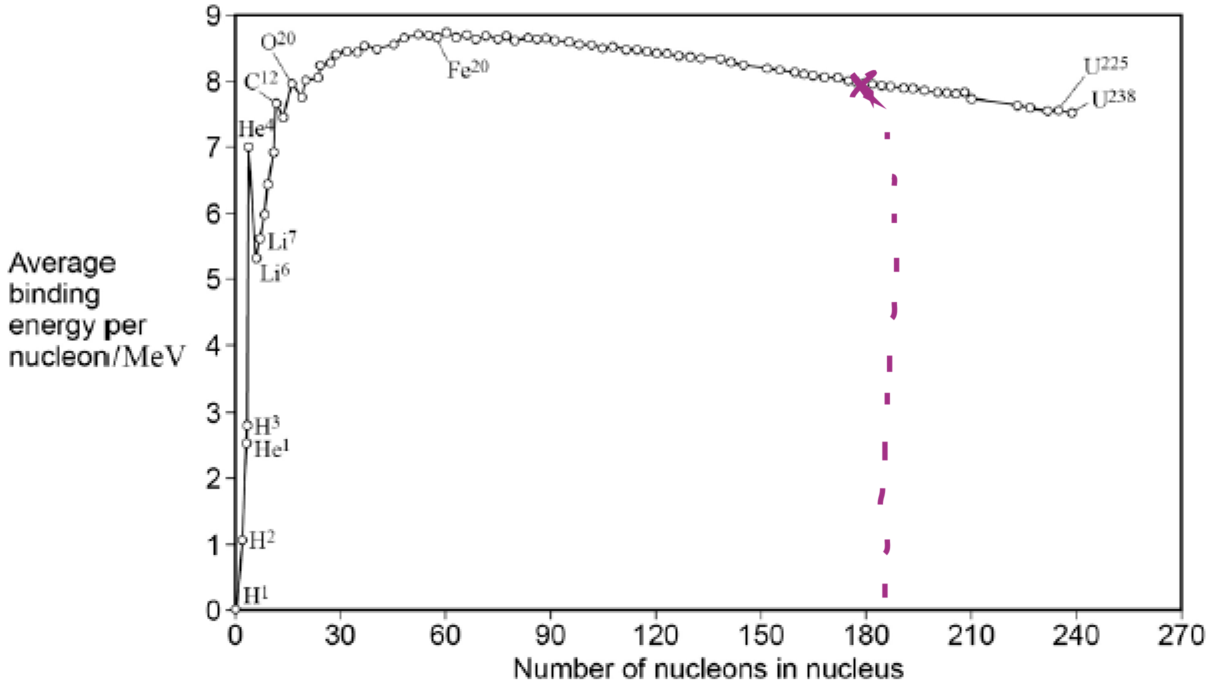
$1 \rightarrow \frac{1}{2} \rightarrow \frac{1}{4} \rightarrow \frac{1}{8} \rightarrow \frac{1}{16}$

so 64 days $= 4 \times t_{\frac{1}{2}}$

A	2 days.	⬭
B	4 days.	⬭
C	8 days.	⬭
D	16 days.	⬭

(Total 1 mark)

7 The graph shows how the binding energy per nucleon varies with the nucleon number for stable nuclei.



What is the approximate total binding energy for a nucleus of $^{184}_{74}W$?

184

≈ 8 MeV/nuc

= 1472 MeV

A	1.28 pJ	⬭
B	94.7 pJ	⬭
C	103 pJ	⬭
D	230 pJ	⬭

E = $1472 \times 10^{6}\,eV \times 1.6 \times 10^{-19}$

2.4×10^{-10} J

(Total 1 mark)

Mark schemes

1 (a) 2.0 cm ✓ (allow 1.96 to 2.00 cm)

(Answer alone gains mark and ignore number of sig. figs)

(The depth halves in 19s. With the graph being exponential the depth will halve every 19s. 57/19 = 3 so the halving occurs 3 times. 16 cm → 8 cm → 4 cm → 2 cm)

1

(b) Use more water/greater depth/greater volume (in the existing cylinder)

(This should give the same half-life) ✓

Assume the word water is present in the answer if there is no reference to it. Eg 'greater depth' is taken as 'greater depth of water'.

1

(c) Closing the tap more

OR

Using a more viscous fluid (density is not the same as viscosity)

OR

Using a wider cylinder

OR

Use a smaller diameter capillary/narrow tube ✓

To decrease the decay constant the depth decrease rate should be reduced ie the cylinder should take longer to empty).

Changes to the tube need to be specific.

Also tube needs to be identified.

1

(d) (Using $T_{½} = \ln 2/\lambda = 0.693/1.42 \times 10^{-11}$)

$T_{½} = 4.9(4.88) \times 10^{10}$ (year) ✓

1

(e) (Use of $N = N_o e^{-\lambda t}$ mass is proportional to number so

$m = m_o e^{-\lambda t}$

$m_o = m\, e^{+\lambda t}$)

$\lambda t = 1.42 \times 10^{-11} \times 4.47 \times 10^{9}$ or 0.0635 ✓

($m_o = 1.23 \times 10^{-3}\, e^{1.42 \times 10^{-11} \times 4.47 \times 10^{9}}$)

$m_o = 1.31 \times 10^{-3}$ (g) ✓(allow and look out for unit being modified to mg)

Mark for 3 sig figs but must be attached to a final answer for mass with some attempt at a relevant exponential calculation ✓

May calculate N = 8.51(2) × 10^{18} and N_0 9.07 × 10^{18} but marks will be the same.

3

(f) (N = mass/87u = $1.23 \times 10^{-6} / (87 \times 1.661 \times 10^{-27})$)

$N = 8.5(1) \times 10^{18}$ ✓

(This does not have to be calculated out for the mark)

($\lambda = 1.42 \times 10^{-11} / (365 \times 24 \times 60 \times 60) = 4.50 \times 10^{-19}$)

($A = \lambda N = 4.50 \times 10^{-19} \times 8.51 \times 10^{18}$)

A = 3.8(4) ✓ (this calculation must use in seconds)

Bq, B/becquerel, counts s^{-1} or s^{-1} ✓

In first mark is obtainable from calculating number of moles and then multiplying by Avogadro's number.

{n = $1.23 \times 10^{-6}/87 = 1.41 \times 10^{-5}$

N = $1.41 \times 10^{-5} \times 6.02 \times 10^{23}$}

A power of 10 error will count as an AE and will allow an error carried forward.

Answer must follow working showing correct process as correct answer can come from incorrect working.

3

[10]

2 **C**

[1]

3 (a) any 2 from:

the sun, cosmic rays, radon (in atmosphere), nuclear fallout (from previous weapon testing), any radioactive leak (may be given by name of incident) nuclear waste, carbon-14 ✓

1

(b) (i) (ratio of area of detector to surface area of sphere)

ratio = $\dfrac{0.0015}{4\pi(0.18)^2}$ ✓

0.0037 ✓ (0.00368)

2

(ii) activity = 0.62/(0.00368 × 1/400) give first mark if either factor is used.

67000 ✓ Bq accept s^{-1} or decay/photons/disintegrations s^{-1} but not counts s^{-1} ✓ (67400 Bq)

3

(c) (use of the inverse square law)

$\dfrac{I_1}{I_2} = \left(\dfrac{r_2}{r_1}\right)^2$ or calculating k = 0.020 from $I = k/x^2$ ✓

$I_2 = 0.62 \times \left(\dfrac{0.18}{0.28}\right)^2$ ✓ 0.26 counts s^{-1} ✓(allow 0.24-0.26)

3

[9]

4 (a) (using mass defect = $\Delta m = Z\,m_p + N\,m_n - M_{Co}$)
Δm = 27 × 1.00728 + 32 × 1.00867 – 58.93320 (u) ✓
Δm = 0.5408 (u) ✓
Binding Energy = 0.5408 × 931.5 = 503.8 (MeV) ✓ (CE this mark stands alone for the correct energy conversion even if more circular routes are followed.

Look at use of first equation and if electrons are used or mass of proton and neutron confused score = 0.

If subtraction is the wrong way round lose 1 mark.

Data may come from rest mass eg m_n =939.551 MeV or 1.675 × 10^{-27} kg or 1.00867 u.

So if kg route used Δm = 8.83 × 10^{-28} kg BE = 7.95 × 10^{-28} J and 497 Mev.

Conversion mark (2nd) may come from a wrong value worked through. 0.47(5)

3

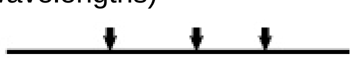
(b) (2.52 – 1.76) × 10^{-13} = 7.6 × 10^{-14} J ✓

7.6 × 10^{-14} / 1.60 × 10^{-13} = 0.47 or 0.48 MeV ✓(0.475 MeV)

Correct answer scores both marks.

2

(c) 6 (specific wavelengths)



1

(d) (longest wavelength = lowest frequency = smallest energy)

$(2.29 \times 10^{-13} - 2.06 \times 10^{-13}) = 2.3 \times 10^{-14}$ (J) ✓

λ (= $h\,c\,/\,E$) = $6.63 \times 10^{-34} \times 3.00 \times 10^{8} / 2.3 \times 10^{-14}$ ✓

λ = 8.6 - 8.7 × 10^{-12} (m) ✓ (8.6478×10^{-12} m)

Allow a CE in the second mark only if the energy corresponds to an energy gap including those to the ground state.

The allowed energy gaps for CE are:

2.29, 2.06, 1.76, 0.53, 0.30 all × 10^{-13}

Note substitution rather than calculation gains mark.

The final mark must be as shown here and not from a CE above.

3

[9]

5 **B**

[1]

6 D

[1]

7 D

[1]