

1. (a) (i) which atom decays **(1)**  
at what time is chance **(1)**
- (ii) isotopes are (different forms) of same element **(1)**  
same proton number,  $Z$ , different nucleon number,  $A$   
[or with same number of protons but different number  
of neutrons] **(1)**

half-life is time for number of nuclei to halve  
[or to halve activity] **(1)**  
for a particular isotope **(1)**

$$\frac{dN}{dt} = -\lambda N \text{ (1)}$$

$\lambda$  is constant of proportionality [or probability of decay] **(1)**  
[or  $\lambda$  is probability of decay **(1)** in unit time **(1)**]

max 6

$$(b) \quad (i) \quad \lambda = \frac{\ln 2}{8.04 \times 24 \times 3600} \text{ (1)} = 1.0 \times 10^{-6} \text{ s}^{-1} \text{ (1)}$$

$$(ii) \quad N = \frac{5.0 \times 10^4}{1.0 \times 10^{-6}} \text{ (1)} = 5.0 \times 10^{10}$$

$$(iii) \quad \ln\left(\frac{N_0}{N}\right) = \lambda t \text{ (1)}$$

$$t = \frac{\ln\left(\frac{5.4 \times 10^{10}}{5.0 \times 10^{10}}\right)}{1.0 \times 10^{-6}} \text{ (1)} = 7.7 \times 10^4 \text{ s (1)}$$

$$= \frac{7.7 \times 10^4}{3600} = 21(4) \text{ (hour) (1)}$$

max 6

**[12]**

2. (a) (i)  ${}_{92}^{238}\text{U} \rightarrow {}_2^4\alpha \text{ (1)} + {}_{90}^{234}\text{Th} \text{ (1)}$
- (ii)  $\Delta m = 238.05076 - 4.00260 - 234.04357 = 0.00459 \text{ (u) (1)}$   
 $Q = 931 \times 0.00459 \text{ (MeV) (1)}$   
 $= 4.3 \text{ MeV (1)}$

5

- (b) (i) overall change in proton number  $(= 92 - 82) = 10$   
change in proton number due to  $\alpha$  particles  $(= 8 \times 2) = 16 \text{ (1)}$   
therefore  $\Delta Z = -6$  for the  $\beta^-$  particles corresponding to the  
six  $\beta^-$  particles **(1)**

- (ii) proton changes to a neutron plus a positron  
 [or  $p \rightarrow n + \beta^+ (+ \nu_e + Q)$ ] (1)  
 Pb-206 has a lower neutron to proton ratio than U-238 (1)  
 $\alpha$  alpha emission raises the neutron to proton ratio slightly (1)  
 $\beta^-$  emission lowers the ratio (more) (1)  
 $\beta^+$  emission increases neutron to proton ratio (1)  
 positron emission competes with  $\alpha$  emission but is energetically less favourable (1)

max 6

[11]

3. (a)  $m = 4.0026 \times 1.66 \times 10^{-27}$  (kg) (1)  
 (=  $6.6 \times 10^{-27}$  kg – electron masses are not significant)  
 kinetic energy ( $= \frac{1}{2} m v^2$ ) =  $0.5 \times 6.65 \times 10^{-27} \times (2.00 \times 10^7)^2$  (1)  
 (=  $1.33 \times 10^{-12}$  J)

2

- (b) loss in k.e. = gain in p.e. (1)

$$\text{loss of ke. [or } 1.33 \times 10^{-12}] = \frac{Qq}{4\pi\epsilon_0 R} \quad (1) \quad \left( = \frac{2Ze^2}{4\pi\epsilon_0 R} \right)$$

$$R = \frac{2 \times 79 \times (1.6 \times 10^{-19})^2}{4\pi \times 8.85 \times 10^{-12} \times 1.33 \times 10^{-12}} \quad (1)$$

$$= 2.73 \times 10^{-14} \text{ m} \quad (1)$$

4

- (c) *any valid point including:*  
 strong force complicates the process (\*)  
 scattering caused by distribution of protons not whole nucleon distribution (\*)  
 $\alpha$  particles are massive causing recoil of nucleus which complicates results (\*)  
 (\*) any **one** (1)

1

[7]

4. (a) (i) proton number = 36 (1)  
 neutron number = 56 (1)

- (ii) krypton (1)

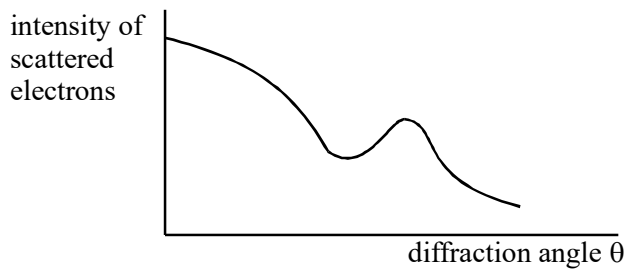
3

- (b) one-fifth efficiency so total output  $(= 10 \times \frac{100}{20} = 50(\text{MW})$  **(1)**  
 energy in one day  $= 50 \times 10^6 \times 24 \times 3600(\text{J})$  **(1)**  $(4.32 \times 10^{12} \text{ J})$   
 fission atoms per day  $= \frac{4.32 \times 10^{12}}{3.2 \times 10^{-11}} = 1.35 \times 10^{23}$  **(1)**

3

**[6]**

5. (a)



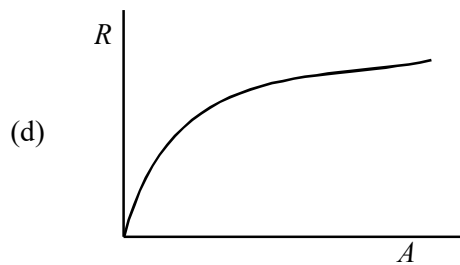
graph shows a minimum **(1)**  
 which does not touch the axis **(1)**

2

- (b) the (de Broglie) wavelength of high energy electrons is comparable to nuclear radii [or not subject to the strong nuclear force] **(1)**
- (c) nuclear density is constant **(1)**  
 separation of neighbouring nucleons is constant [or nucleons are close-packed] **(1)**

1

2



correct curve **(1)**

1

(e)  $R = r_0 A^{\frac{1}{3}}$  (1)

$$R_0 \left( = R_c \left( \frac{A_0}{A_c} \right)^{\frac{1}{3}} \right) = 3.04 \times 10^{-15} \times \left( \frac{16}{12} \right)^{\frac{1}{3}} \text{ (1)}$$

$R_0 = 3.35 \times 10^{-15} \text{ m}$  (1)

3

[9]

6. (a) time for half of (active) nuclei (of radioactive substance) to decay (1) 1

(b)

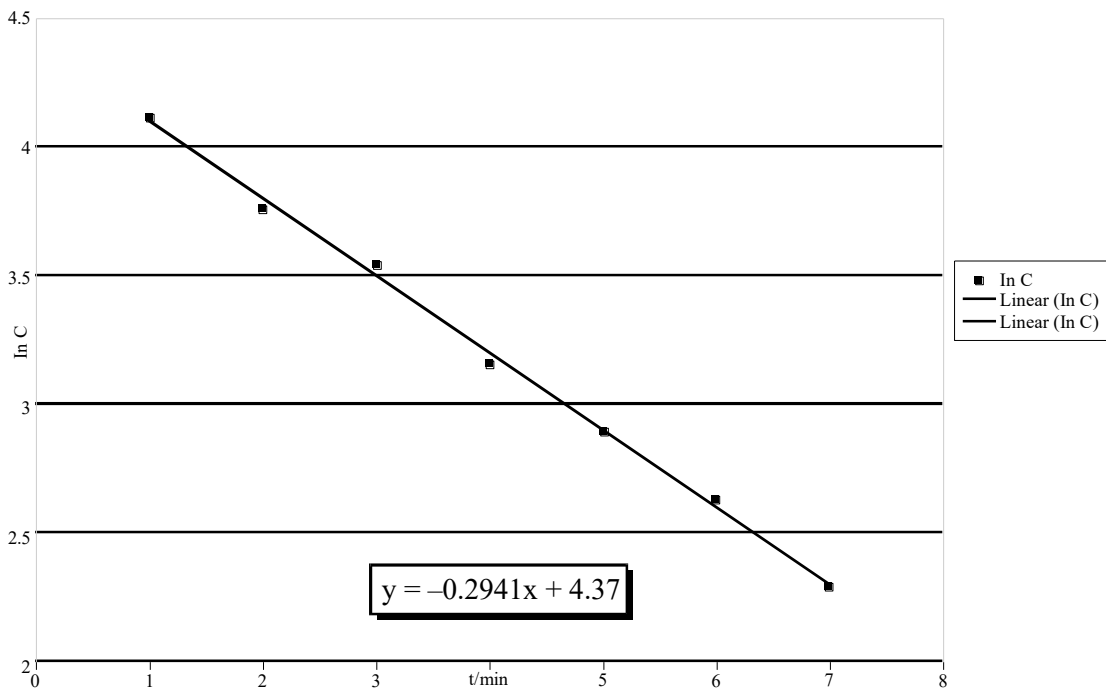
t/minute	0	10	20	30	40	50	60
number of counts in 30s, C	60	42	35	23	18	14	10
ln C	4.094	3.738	3.555	3.135	2.890	2.639	2.303

Correct values of ln C above (1)

1

(c) (i) seven points correctly plotted (1) (1) [six points correct (1)]

graph of lnC against time



(ii) best straight line through points (1)

sensible scale (1)

(iii) from sensible triangle on graph **(1)**  
 gradient = - **(1)** 0.030 [0.294] **(1)** ( $\text{min}^{-1}$ ) ( $\text{min}^{-1}$ ) max 5

(d) (i)  $C = C_0 e^{-\lambda t}$ ,  $\ln C - \ln C_0 = -\lambda t$   
 hence using  $y = mx + c$ ,  $\lambda = (-)\text{gradient}$  **(1)**

(ii) half-life =  $\frac{\ln 2}{\lambda} = \frac{0.693}{0.03}$  **(1)** = 23 min **(1)** 3

(e) count over longer period than half minute [or repeat experiment] **(1)**  
 use stronger source **(1)**  
 use background count correctly **(1)** max 2

(f) for  $^{14}\text{C}$ ,  $\lambda = \frac{0.693}{T_{1/2}} = 1.21 \times 10^{-4}$  (year) **(1)**

$-\lambda t \left( = \ln \frac{R}{R_0} \right) = \ln \left( \frac{5.2}{6.5} \right)$  **(1)** = -0.223 **(1)**

$t = \frac{0.223}{1.21 \times 10^{-4}} = 1840$  (year) **(1)** 4

**[16]**

7. (a) (i)  $^{40}_{19}\text{K} + e^- \rightarrow ^{40}_{18}\text{Ar}$  **(1)** +  $\nu_{(e)}$  **(1)** (+Q)

(ii)  $\Delta m = 39.96401 - 39.96238 = 0.00163$  u **(1)**  
 $Q (= 0.00163 \times 931) = 1.5$  (MeV) **(1)**

(iii) orbital electron vacancy due to electron capture **(1)**  
 outer electron fills vacancy and emits X – ray photon **(1)** max 5

- (b) (i)  ${}_{19}^{40}\text{K} \rightarrow {}_{20}^{40}\text{Ca} + \text{e}^{-} \text{ (1)} + \overline{\nu}_{\text{(e)}} \text{ (1)}$
- (ii) use of beta emission 8 times more probable than electron capture **(1)**  
 use of number of potassium atoms equals 5 times number of  
 argon atoms **(1)**  
 leading to evaluation of 36% **(1)**  
 use of the decay equation **(1)**  
 correct answer **(1)**  
*for example:*  
 14 atoms of K-40 originally  
 becomes 8 atoms of Ca-40 + 1 atom of Ar-40 + 5 atoms K-40 unchanged  
 36% of K-40 not decayed
- use  $N = N_0 e^{-\lambda t}$  to give  $t = \frac{-T_{1/2} \ln 0.36}{\ln 2} = 1860 \times 10^6 \text{ yr}$  max 4

**[9]**

8. (a) (i) alpha **(1)**  
 (ii) two different track lengths **(1)**  
 short range particles have lower energy than long range particles **(1)**  
 particles in each range have same energy **(1)** 4
- (b) (i)  ${}_{94}^{239}\text{Pu} \rightarrow {}_{92}^{235}\text{U} + \alpha \text{ (1)} (+Q)$   
 (ii)  ${}_{92}^{235}\text{U} \rightarrow {}_{90}^{231}\text{Th} + \alpha \text{ (1)} (+Q)$   
 (iii) U-235 **(1)**  
 because of the inverse relationship  
 between half-life and alpha particle energy **(1)**  
 (iv) because the Th-90 nucleus is neutron-rich compared  
 with U-235 [or Pu-239] **(1)** 5

**[9]**

9. (a) (i)  $T_{1/2} = 50 \text{ s}$  (1) (from graph)
- (ii)  $\lambda = \frac{\ln 2}{50}$  (1) =  $0.014 \text{ s}^{-1}$  (1)
- (iii)  $N = \frac{A_0}{\lambda}$  (1) =  $\frac{2.4 \times 10^5}{0.014} = 1.7(1) \times 10^7$  (1) 5

- (b) (i) elapsed time = 50s = 1 half-life (1)  
 $N_{30} = N_0 e^{-30\lambda}$  (1) =  $1.71 \times 10^7 e^{-30 \times 0.014} = 1.12 \times 10^7$  (1)  
 $\therefore$  no. decayed from  $t = 30\text{s}$  to  $t = 80\text{s}$  is  $\frac{1.12 \times 10^7}{2} = 0.56 \times 10^7$  (1)

[alternative (b)(i)]

$N_{30} = N_0 e^{-30\lambda}$  and  $N_{80} = N_0 e^{-80\lambda}$  (1)

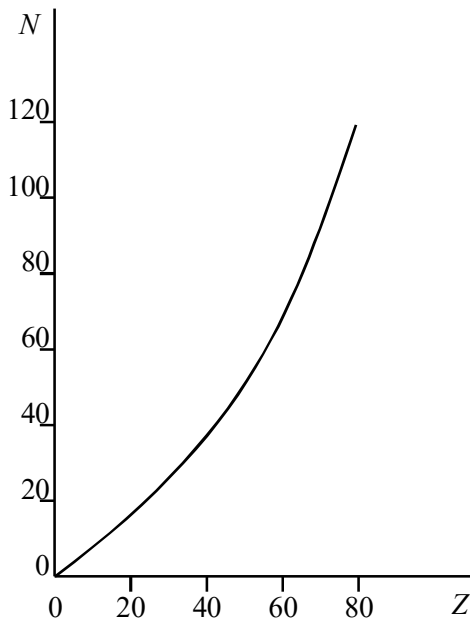
give  $1.12 \times 10^7$  (1) and  $0.56 \times 10^7$  (1)

number decayed (=  $1.12 \times 10^7 - 0.56 \times 10^7$ ) =  $0.56 \times 10^7$  (1)

- (ii) energy released =  $0.56 \times 10^7 \times 1.0 \times 10^{-12} = 5.6 \times 10^{-6} \text{ J}$  (1) max 4

[9]

10. (a)



straight line between  $(Z = 0, N = 0)$  to  $(Z = 20, N = 20)$  (1)

curving upwards to  $Z = 80; N = 110 - 130$  (1)

2

- (b) (i) A = any region below the line of stability  
but  $N > 80$  and  $Z > 60$
- (ii) B = any region above and close to the line of stability **(1)**
- (iii) C = any region below and close to the line of stability **(1)**

3

(c)

mode of decay	change in proton number, $Z$	change in neutron number, $N$
$\alpha$ emission	-2	-2
$\beta^-$ emission	+1	-1
$\beta^+$ emission	-1	+1
e capture	-1	+1
p emission	-1	0
n emission	0	-1

**(1)(1)(1)** – lose one mark for each row in error

3

**[8]**

11. (a) ( $R^3 = R_0^3 A$ )  
plot  $R^3$  against  $A$  with axes labelled **(1)**  
units on axes **(1)**  
scales chosen to use more than 50% of page **(1)**

element	$R/10^{-15}$ m	$A$	$R^3/10^{-45}$ m <sup>3</sup>
carbon	2.66	12	18.8
silicon	3.43	28	40.4
iron	4.35	56	82.3
tin	5.49	120	165.5
lead	6.66	208	295

calculate data for table **(1)**  
plot data **(1)(1)** lose one mark for each error  
calculation of gradient



$$\text{e.g. gradient} = \frac{300 \times 10^{-45}}{213} \quad (1) \quad (= 1.41 \times 10^{-45} \text{ m}^3)$$

$$r_0 (= \text{gradient})^{1/3} \quad (1)$$

$$= (1.41 \times 10^{-45})^{1/3} = 1.1(2) \times 10^{-15} \text{ m} \quad (1)$$

*alternative:*

plot  $R$  against  $A^{1/3}$  with axes labelled (1)

units on axes (1)

scales chosen to use more than 50% of page (1)

element	$R/10^{-15} \text{ m}$	$A$	$A^{1/3}$
carbon	2.66	12	2.29
silicon	3.43	28	3.04
iron	4.35	56	3.83
tin	5.49	120	4.93
lead	6.66	208	5.93

calculate data for table (1)

plot data (1)(1) lose one mark for each error

calculation of gradient

$$\text{e.g. gradient} = \frac{6.72 \times 10^{-15}}{6.0} \quad (1) \quad (= 1.1(2) \times 10^{-15} \text{ m}^3)$$

$$r_0 = \text{gradient} \quad (1)$$

$$= 1.1(2) \times 10^{-15} \text{ m} \quad (1)$$

[or plot  $\ln R$  against  $\ln A$ ...]

max 8

- (b) assuming the nucleus is spherical  
 ignoring the gaps between nucleons  
 assuming all nuclei have same density  
 assuming total mass is equal to mass of constituent nucleus  
 any one assumption (1)

$$M = \frac{4}{3} \pi R^3 \rho \quad (1)$$

$$\left( \therefore M = \frac{4}{3} \pi R_0^3 a \rho \right)$$

$$\left( \therefore \rho = \frac{3m}{4\pi R_0^3} \right) = \frac{3 \times 1.67 \times 10^{-27}}{4\pi \times (1.12 \times 10^{-15})^3} \quad (1)$$

$$= 2.8 \times 10^{17} \text{ kgm}^{-3} \quad (1)$$

4

[12]

12. (a) (i) (inner) orbiting electron [or electron surrounding the nucleus] (1)  
 captured by a proton (in the nucleus) (1)  
 converted into a neutron (1) QWC
- (ii) daughter nuclide/nucleus/atom might be excited and  
 energy given up as electromagnetic radiation  
 [or orbiting electrons drop down to fill space  
 (left by captured electron)] (1) QWC
- (iii)  ${}_{83}^{203}\text{Bi} \rightarrow {}_{82}^{203}\text{Pb} + {}_1\beta^+ \quad (1) + \nu_{(e)} \quad (1) (+Q)$  [allow  ${}_1^0\text{e}^+$  for  ${}_1\beta^+$ ] max 5
- (b) (i) (use of  $N = N_0 e^{-\lambda t}$  and  $N \propto$  activity gives)  
 $290 = 1200 \exp(-\lambda \times 24 \times 60 \times 60) \quad (1)$   
 $\lambda = \frac{\ln(1200/290)}{24 \times 60 \times 60} \quad (1) (= 1.64 \times 10^{-5} \text{ s}^{-1})$
- (ii) (use of  $T_{1/2} = \ln 2 / \lambda$  gives)  $T_{1/2} = \frac{\ln 2}{1.64 \times 10^{-5}} \quad (1)$   
 $= 4.2(3) \times 10^4 \text{ s} \quad (1) (= 11.(7) \text{ hr})$   
 (use of  $\lambda = 1.6 \times 10^{-5} \text{ s}^{-1}$  gives  $T_{1/2} = 4.3 \times 10^4 \text{ s}$  or 12 hr)
- (iii) (use of  $\frac{\Delta N}{\Delta t} = \lambda N$  gives)  $(-1200 = (-)1.64 \times 10^{-5} N) \quad (1)$   
 $N = 7.3(2) \times 10^7 \text{ (nuclei)} \quad (1)$   
 (use of  $\lambda = 1.6 \times 10^{-5} \text{ s}^{-1}$  gives  $N = 7.5 \times 10^7 \text{ (nuclei)}$ ) max 5

[10]

13. (a) induced fission: (large) nucleus splits unto two (smaller nuclei) **(1)**  
 brought about by bombardment or collision **(1)**  
 thermal neutrons have low energies or speeds ( $< 1 \text{ eV}$ ) **(1)** 3
- (b) (i)  $N = 3$  **(1)**
- (ii) released neutrons have high(er) energies or speeds **(1)**
- (iii)  $\Delta m = 234.99333 - (91.90645 + 140.88354) - (2 \times 1.00867)$  **(1)**  
 $= 0.186 \text{ u}$  **(1)**  
 (if last term in  $\Delta m$  omitted or incorrect number of neutrons  
 used in calculation, treat answer as C.E.)  
 energy released  $= 0.186 \times 931 = 173 \text{ MeV}$  **(1)**  
 (allow C.E. for  $\Delta m$ ) 5
14. (a) (i)  $\alpha$  (radiation) **(1)**
- (ii)  $\gamma$  (radiation) **(1)** 2
- (b) (i) the radiation needs to pass through the body (to be detected) **(1)**
- (ii) (otherwise) the activity of the source becomes too weak  
 (during measurements) **(1)**
- (iii) the decaying source may remain in the body for a long time  
 and could cause damage **(1)**  
 [or the activity of the source will be low unless a large  
 quantity is used ( $T_{1/2} \propto 1/\lambda$ )] 3

**[8]**

- (c) corrected count rate at 0.2 m (= 2550 – 50) = 2500 (c min<sup>-1</sup>) **(1)**  
 corrected count rate at least distance (= 6000 – 50) = 5950 (c min<sup>-1</sup>) **(1)**

use of  $I = k \frac{I_0}{x^2}$  (or in the form  $\frac{I_1}{I_2} = \left(\frac{x_2}{x_1}\right)^2$ ) **(1)**

(allow C.E. for using uncorrected count rate)

gives least distance =  $0.20 \times \left(\frac{2500}{5950}\right)^{1/2}$  **(1)**

least distance = 0.13 m **(1)**

5

**[10]**

15. (a) (i) thick  
 high density  
 material giving minimal fatigue problems after irradiation  
 any other sensible property e.g. withstands high temperature  
 any two **(1) (1)**

- (ii) (reinforced) concrete **(1)**

3

- (b) effect of shielding:  
 $\gamma$  rays - intensity (greatly) reduced **(1)**  
 neutrons - some absorption **(1)**  
 (or speed or energy reduced by collisions) **(1)**  
 neutrinos - very little effect **(1)**

why shielding becomes radioactive:

- neutron absorption by nuclei or atoms **(1)**  
 makes nuclei (not particles) neutron rich or unstable **(1)**  
 become  $\beta^-$  emitters and/or  $\gamma$  emitters

max 4  
 QWC 2

**[7]**

16. (a) (use of 'isotope' instead of 'nucleus' not accepted)  
 there is equal probability of any nucleus decaying,  
 it cannot be known which particular nucleus will decay next,  
 it cannot be known at what time a particular nucleus will decay,  
 the rate of decay is unaffected by the surrounding conditions,  
 it is only possible to estimate the proportion of nuclei decaying  
 in the next time interval

any two statements **(2)**

2  
 QWC 2

- (b) continuous curve starting at  $5.5 \times 10^5$  Bq  
 plus correct 1st half-life (2.6 yrs,  $2.75 \times 10^5$  Bq) **(1)**  
 correct 2nd half-life (5.2 years,  $1.4 \times 10^5$  Bq) **(1)**  
 (allow C.E. for incorrect 1st half-life)

2

(c) (i) (use of  $T_{1/2} = \frac{\ln 2}{\lambda}$  gives)  $\lambda = \frac{\ln 2}{2.6 \times 3.15 \times 10^7}$  **(1)**  
 $= 8.5 \times 10^{-9} \text{ (s}^{-1}\text{)}$  **(1)**  
 ( $8.46 \times 10^{-9} \text{ (s}^{-1}\text{)}$ )

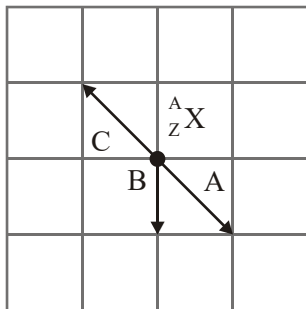
(ii) (use of  $\frac{dN}{dt} = -\lambda N$  gives)  $N = \frac{5.5 \times 10^5}{8.5 \times 10^{-9}}$  **(1)**  
 $= 6.5 \times 10^{13}$  (atoms) **(1)**  
 (allow C.E. for value of  $\lambda$  from (i))

(iii) (use of  $N = N_0 e^{-\lambda t}$  and  $A \propto N$  gives)  
 $t \left( = \frac{\ln(A_0 / A)}{\lambda} \right) = \frac{\ln(1.0 \times 10^5 / 0.75 \times 10^5)}{8.5 \times 10^{-9}}$  **(1)**  
 $= 3.4 \times 10^7$  (s) **(1)**  
 (allow C.E. for value of  $\lambda$  from (i))

6

**[10]**

17. (a) (i)



correct arrows: A **(1)**  
 B **(1)**  
 C **(1)**

(ii)  $e^{-1} + {}^A_Z X \rightarrow {}^A_{Z-1} Y + \nu_e$  **(1)**

4

- (b) (i)  $((4.18 - 1.33) \times 10^{-13}) = 2.85 \times 10^{-13}$  (J) (1)
- (ii)  $1.33 \times 10^{-13}$  (J)  
 $0.30 \times 10^{-13}$  (J) for 3 correct values (1)  
 $1.63 \times 10^{-13}$  (J)
- (iii) (use of  $\Delta E = hf$  gives)  $f \left( \frac{1.63 \times 10^{-13}}{6.63 \times 10^{-34}} \right) = 2.46 \times 10^{20}$  Hz (1)  
 (allow C.E. from (b)(ii) if largest value taken) 3

- (c) (i) ((1) for each precaution with reason to  $\text{max} 2$ )  
 handle with (long) (30 cm) tweezers  
 because the radiation intensity decreases with distance  
 store in a lead box (immediately) when not in use to avoid  
 unnecessary exposure to radiation  
 [or any sensible precaution with reason] QWC 2
- (ii)  $\gamma$  rays are more penetrating and are therefore more hazardous  
 (to the internal organs of the body)  
 $\beta^-$  particles are more hazardous because they are more ionising (1)  
 ((1) for any argued case for either radiation) 3

[10]

18. (a) (on grid: first arrow to start from  ${}_{82}^{210}\text{Pb}$ ; arrows must be consecutive;  
 last arrow must end on  ${}_{82}^{206}\text{Pb}$ )  
 arrow showing the change for an  $\alpha$  emission (1)  
 arrow showing the change for a  $\beta$  emission (1)  
 correct  $\alpha$  and two  $\beta$  emissions in any order (1) 3
- (b) (positron emission)  ${}_{29}^{64}\text{Cu} \rightarrow {}_{28}^{64}\text{Ni} + \beta^+ + \nu_e (+Q)$  (1) (1)  
 (electron capture)  ${}_{29}^{64}\text{Cu} + {}_{-1}^0e \rightarrow {}_{28}^{64}\text{Ni} + \nu_{(e)} (+Q)$  (1) (1) 4

(c) (the following examples may be included)

$\alpha$  particles (1)

coulomb/electrostatic/electromagnetic repulsion

[or K.E. converted to P.E. (as  $\alpha$  particle approaches nucleus)] (1)

information:

any of the following: proton number, nuclear charge,  
upper limit to nuclear radius  
mass of nucleus is most of the mass  
of atom (1)

[alternative

(high energy) electron (scattering) (1)

diffraction of de Broglie Waves by nucleus (1)

information:

any of the following: nuclear radius, nuclear density (1)

3  
QWC 2

[10]

19. (a) (i) origins of background radiation: cosmic rays  
ground, rocks and buildings  
air  
nuclear weapons testing/nuclear accidents  
nuclear power  
discharge/waste from nuclear power  
medical waste

any three (1) (1)

any two (1)

(ii) (use of  $C = C_0 e^{-\lambda t}$  gives)  $(84 - 3) = (110 - 3) e^{-\lambda \times 600}$  (1)

$$\lambda = \frac{\ln(107/81)}{600} \quad (1)$$

$$= 4.6(4) \times 10^{-4} \text{ (s}^{-1}\text{)} \quad (1)$$

(iii) (use of  $\frac{dN}{dt} = -\lambda N$  gives)  $N = \frac{107}{4.64 \times 10^{-4}}$  (1)

$$= 2.3(1) \times 10^5 \text{ (nuclei)} \quad (1)$$

(allow C.E. for value of  $\lambda$  from (ii)

7

- (b)  $\alpha$  radiation is highly **ionising**, hence causes cancer/damage cells/  
DNA/kill cells (1)

**outside:** less damage plus reason

(e.g. absorbed by dead skin some  $\alpha$ 's directed away from body) (1)  
[or reference to burning]

**inside:** more damage plus reason

(e.g. all  $\alpha$ 's absorbed living tissue will absorb  $\alpha$  radiation can reach  
vital organs) (1)

3  
QWC 1

[10]

20. (a) graph to show:  
electron intensity decreasing with angle of diffraction (1)  
to a non-zero first minimum (1)

2

- (b) (i) last column of table completed correctly (1)  
with either

$A^{1/3}$
5.93
4.93
3.83
3.04
2.29

or

$R^3/(10^{-45}m^3)$
295
165
82.3
40.4
18.8

axes cover more than 50% of graph sheet (1)

all points plotted correctly using labelled axes

(i.e.  $x$ -axis  $A^{1/3}$ ,  $y$ -axis  $R/10^{-15}m$  or  $x$  axis  $A$ ,  $y$ -axis  $R^3/10^{-45}m^3$ ) (1)

- (ii) gradient =  $r_0$  (1) [or gradient =  $r_0^3$ ]  
gives  $r_0 = (1.1 \pm 0.1) \times 10^{-15}m$  (1)

5



- (c) electrons are not subject to the strong nuclear force **(1)**  
(so) electron scattering patterns are easier to interpret **(1)**  
electrons give greater resolution  
[or electrons are more accurate because they can get closer]  
[or  $\alpha$  particles cannot get so close to the nucleus because of  
electrostatic repulsion] **(1)**  
electrons give less recoil **(1)**  
(high energy) electrons are easier to produce  
[or electrons have a lower mass/ larger  $Q/m$ , so easier to accelerate] **(1)**  
(in Rutherford scattering) with  $\alpha$  particles, the closest distance  
of approach, not  $R$  is measured **(1)**

max 3  
QWC 1

[10]

21. (a) graph passes through  $N = 10/11$  when  $Z = 10$  and  $N$  increases as  $Z$   
increases **(1)**  
 $N = 115 \rightarrow 125$  when  $Z = 80$  and graph must bend upwards **(1)** 2
- (b) (i) **W** at  $Z > 60$  just (within one diagonal of a square) below line **(1)**  
(ii) **X** just (within one diagonal of a square) above line **(1)**  
(iii) **Y** just (within one diagonal of a square) below line **(1)** 3
- (c) working showing the change due to emission of four  $\alpha$  particles **(1)**  
four  $\beta^-$  particles **(1)** 2

(d) Any **two** from the following list of processes:

$\beta^+$

describe the changes to  $N$  (up by 1) and  $Z$  (down by 1)

[or allow p change to n]

$\alpha$

move closer to line of stability

[or state the proton to neutron ratio is reduced]

p

only if nuclide is **very** proton rich

[or electrostatic repulsion has to overcome the strong nuclear force]

[or highly unstable]

[or rare process]

$e^-$  capture

describe the changes to  $N$  (up by 1) and  $Z$  (down by 1)

allow p changes to n

marking: listing **two** processes **(1)**

discussing **each** of the two processes **(1) (1)**

3  
QWC 1

[10]

22. (a) reasons:

$\alpha$  particle has much more mass/momentum than  $\beta$  particle

$\alpha$  particle has twice as much charge as a  $\beta$  particle

$\alpha$  particle travels much slower than a  $\beta$  particle any **two (1) (1)**

2  
QWC 1

(b) (i) energy absorbed per sec (= energy released per sec)

$$= 3.2 \times 10^9 \times 5.2 \times 10^6 \times 1.6 \times 10^{-19} \text{ (1)}$$

$$= 2.7 \times 10^{-3} \text{ (J) (1) } (2.66 \times 10^{-3} \text{ (J)})$$

(ii) temperature rise in 1 minute  $\left( = \frac{\text{energy absorbed in 1 minute}}{\text{mass} \times \text{specific heat capacity}} \right)$

$$= \frac{2.7 \times 10^{-3} \times 60}{0.20 \times 10^{-3} \times 900} \text{ (for numerator) (1) (for denominator) (1)}$$

$$= 0.90 \text{ K (or } ^\circ\text{C) (1)}$$

(allow C.E. for incorrect value in (i))

5

[7]

23. (a)  $R (= r_0 A^{1/3}) = 1.3 \times 10^{-5} \times (238)^{1/3} \text{ (1)}$

$$= 8.0(6) \times 10^{-15} \text{ m (1)}$$

2

- (b) (use of inverse square law e.g.  $\frac{I_1}{I_2} = \left(\frac{x_1}{x_2}\right)^2$  gives)

$$10 = \left(\frac{x_2}{0.03}\right)^2 \quad (1)$$

$$x = 0.095 \text{ m} \quad (1)$$

(0.0949 m)

2

- (c) (use of  $A = A_0 \exp(-\lambda t)$  gives)  $0.85 = 1.0 \exp(-\lambda 52)$  (1)

$$\lambda = \frac{\ln(100/0.85)}{52} \quad (1)$$

$$= 3.1(3) \times 10^{-3} \text{ s}^{-1} \quad (1)$$

3

- (d) it only emits  $\gamma$  rays (1)  
 relevant properties of  $\gamma$  radiation e.g. may be detected outside the body/weak ioniser and causes little damage (1)  
 it has a short enough half-life and will not remain active in the body after use (1)  
 it has a long enough half-life to remain active during diagnosis (1)  
 the substance has a toxicity that can be tolerated by the body (1)  
 it may be prepared on site (1)

any three (1)(1)(1)

3

[10]

24. (a) graph passes through  $N = 100$  to  $130$  when  $Z = 80$  (1)  
 and  $N = 20$  when  $Z = 20$  (1)

2

- (b) (i) W at  $Z > 60$  just below line (1)  
 (ii) X just above line (1)  
 (iii) Y just below line (1)

3

- (c) fission nuclei (or fragments) are neutron-rich and therefore unstable (or radioactive) (1)  
 neutron-proton ratio is much higher than for a stable nucleus (of the same charge (or mass)) (1)  
 $\beta^-$  particle emitted when a neutron changes to a proton (in a neutron-rich nucleus) (1)

3

- (d) The marking scheme for this part of the question includes an overall assessment for the Quality of Written Communication (QWC). There are no discrete marks for the assessment of written communication but the quality of written communication will be one of the criteria used to assign the answer to one of three levels.

<b>Level</b>	<b>Descriptor</b>	<b>Mark range</b>
	an answer will be expected to meet most of the criteria in the level descriptor	
<b>Good 3</b>	<ul style="list-style-type: none"> <li>– answer supported by appropriate range of relevant points</li> <li>– good use of information or ideas about physics, going beyond those given in the question</li> <li>– argument well structured with minimal repetition or irrelevant points</li> <li>– accurate and clear expression of ideas with only minor errors of spelling, punctuation and grammar</li> </ul>	<b>5-6</b>
<b>Modest 2</b>	<ul style="list-style-type: none"> <li>– answer partially supported by relevant points</li> <li>– good use of information or ideas about physics given in the question but limited beyond this</li> <li>– the argument shows some attempt at structure</li> <li>– the ideas are expressed with reasonable clarity but with a few errors of spelling, punctuation and grammar</li> </ul>	<b>3-4</b>
<b>Limited 1</b>	<ul style="list-style-type: none"> <li>– valid points but not clearly linked to an argument structure</li> <li>– limited use of information or ideas about physics</li> <li>– unstructured</li> <li>– errors in spelling, punctuation and grammar or lack of fluency</li> </ul>	<b>1-2</b>
<b>0</b>	– incorrect, inappropriate or no response	<b>0</b>

examples of the sort of information or ideas that might be used to support an argument:

- reduction of greenhouse gas emissions is (thought to be) necessary to stop global warming **(1)**
- long term storage of radioactive waste is essential because the radiation from it damages (or kills) living cells **(1)**
- radioactive isotopes with very long half lives are in the used fuel rods **(1)**
- nuclear power is reliable because it does not use oil or gas from other countries **(1)**
- radioactive waste needs to be stored in secure and safe conditions for many years **(1)**

**conclusion****either**

nuclear power is needed; reduction of greenhouse gases is a greater problem than the storage of radioactive waste because

- 1 global warming would cause the ice caps to melt/sea levels to rise **(1)**
- 2 safe storage of radioactive waste can be done **(1)**

**or**

nuclear power is not needed; storage of radioactive waste is a greater problem than reduction of greenhouse gases because

- 1 radioactive waste has to be stored for thousands of years **(1)**
- 2 greenhouse gases can be reduced using renewable energy sources **(1)**

**[14]**

25. (a) number of gamma photons per second =  $\frac{3.0 \times 10^7}{5}$  ( $= 6.0 \times 10^6$ ) **(1)**

area of sphere of radius 1.50m ( $= 4\pi r^2 = 4\pi \times 1.5^2$ ) =  $28.3\text{m}^2$  **(1)**

number of gamma photons per sec per  $\text{cm}^2 = \frac{6.0 \times 10^6}{28.3 \times 10^4}$  **(1)** ( $= 21(.2)$ ) 3

(b) (i) decay constant =  $\left(\frac{\ln 2}{t_{1/2}} = \frac{0.693}{12 \times 3600}\right) = 1.60 \times 10^{-5} \text{ s}^{-1}$  **(1)**

new no. of gamma photons per sec per  $\text{cm}^2 = 21(.2) e^{-(1.6 \times 10^{-5} \times 6.0 \times 3600)}$  **(1)**  
 $= 15(.0)$  **(1)**

(or 6 hours is 0.5 half-lives **(1)** source activity decreases to  $2^{-0.5}$  of initial activity in this time **(1)**)

new no. of gamma photons per sec per  $\text{cm}^2 = 21(.2) \times 2^{-6/12}$  **(1)**  
 $= 15(.0)$  **(1)**

(ii) any **two** of the following points **(1)(1)**

beta particle range in air is less than 1.5m

beta particle absorbed by air

beta particles lose energy in air more rapidly than gamma photons

beta particles ionise air much more than gamma photons

5

**[8]**