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)**

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

λ is constant of proportionality [or probability of decay] **(1)**
[or λ is probability of decay **(1)** in unit time **(1)**] max 6

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

(ii) $N = \dfrac{5.0 \times 10^{4}}{1.0 \times 10^{-6}}$ **(1)** $= 5.0 \times 10^{10}$

(iii) $\ln\left(\dfrac{N_0}{N}\right) = \lambda t$ **(1)**

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

$= \dfrac{7.7 \times 10^{4}}{3600} = 21(.4)$ (hour) **(1)** max 6

[12]

2. (a) (i) ${}^{238}_{92}\text{U} \rightarrow {}^{4}_{2}\alpha$ **(1)** $+ {}^{234}_{90}\text{Th}$ **(1)**

(ii) $\Delta m = 238.05076 - 4.00260 - 234.04357 = 0.00459$(u) **(1)**
$Q = 931 \times 0.00459$ (MeV) **(1)**
= 4.3MeV **(1)** 5

(b) (i) overall change in proton number (= 92 – 82) = 10
change in proton number due to α particles (= 8 × 2) = 16 **(1)**
therefore $\Delta Z = -6$ for the β^- particles corresponding to the
six β^- 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)**
α alpha emission raises the neutron to proton ratio slightly **(1)**
β^- emission lowers the ratio (more) **(1)**
β^+ emission increases neutron to proton ratio **(1)**
positron emission competes with α emission but is
energetically less favourable **(1)** max 6

[11]

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

(b) loss in k.e. = gain in p.e. **(1)**
loss of ke. [or 1.33×10^{-12}] = $\frac{Qq}{4\pi\varepsilon_0 R}$ **(1)** $\left(= \frac{2Ze^2}{4\pi\varepsilon_0 R} \right)$

$R = \frac{2 \times 79 \times (1.6 \times 10^{-19})^2}{4\pi \times 8.85 \times 10^{-12} \times 1.33 \times 10^{-12}}$ **(1)**
$= 2.73 \times 10^{-14}$ m **(1)** 4

(c) *any valid point including*:
strong force complicates the process (*)
scattering caused by distribution of protons not whole nucleon distribution (*)
α 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

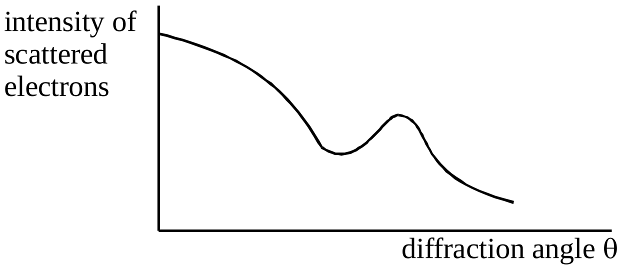
(b) one-fifth efficiency so total output (= $10 \times \frac{100}{20}$ = 50(MW) **(1)**

energy in one day = $50\times 10^6 \times 24 \times 3600$(J) **(1)** ($4.32 \times 10^{12}$ J)

fission atoms per day = $\frac{4.32\times10^{12}}{3.2\times10^{-11}}$ $=1.35 \times10^{23}$ **(1)** 3

[6]

5. (a)

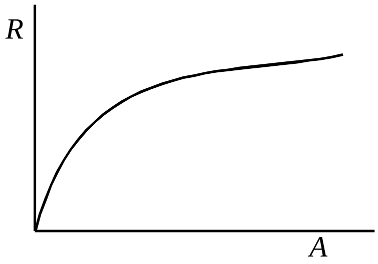


graph shows a minimum **(1)**
which does not touch the axis **(1)** 2

(b) the (de Broglie) wavelength of high energy electrons is comparable to nuclear radii [or not subject to the strong nuclear force] **(1)** 1

(c) nuclear density is constant **(1)**
separation of neighbouring nucleons is constant
[or nucleons are close-packed] **(1)** 2

(d)



correct curve **(1)** 1

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

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

$R_0 = 3.35 \times 10^{-15}$ m **(1)** 3

[9]

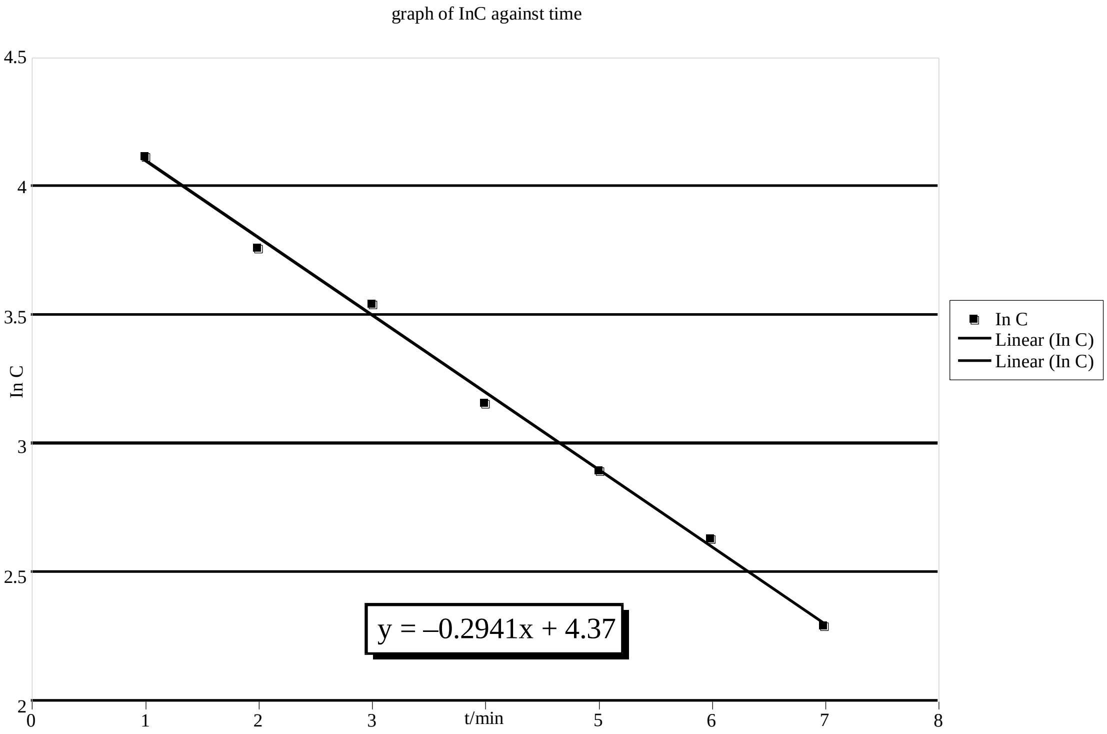
6. (a) time for half of (active) nuclei (of radioactive substance) to decay **(1)** 1

(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)**]



(ii) best straight line through points **(1)**

sensible scale **(1)**

(iii) from sensible triangle on graph **(1)**

gradient **=– (1)** 0.030 [0.294] **(1)** (min $^{-1}$) (min $^{-1}$) max 5

(d) (i) $C = C_0 e^{-\lambda t}$, ln C – ln $C_0 = -\lambda t$
hence using $y = mx + c$, λ = (–)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}C, $\lambda = \frac{0.693}{T_{1/2}}$ =1.21 × 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) ${}^{40}_{19}\text{K} + \text{e}^- \rightarrow {}^{40}_{18}\text{Ar}$ **(1)** + $\nu_{(\text{e})}$ **(1)** (+Q)

(ii) Δm = 39.96401 – 39.96238 = 0.00163 u **(1)**

Q(= 0.00163 × 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) ${}^{40}_{19}\text{K} \rightarrow {}^{40}_{20}\text{Ca} + e^{-}$ **(1)** + $\overline{v_{(e)}}$ **(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 $t = \dfrac{-T_{1/2} \ln 0.36}{\ln 2} = 1860 \times 10^{6}$ 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) ${}^{239}_{94}\text{Pu} \rightarrow {}^{235}_{92}\text{U} + \alpha$ **(1)** (+Q)

(ii) ${}^{235}_{92}\text{U} \rightarrow {}^{231}_{90}\text{Th} + \alpha$ **(1)** *(+Q)*

(iii) U–235 **(1)**

because of the <u>inverse</u> relationship
between half–life and alpha particle energy **(1)**

(iv) because the Th–90 nucleus is neutron–rich <u>compared</u>
with U–235 [or Pu–239] **(1)** 5

[9]

9. (a) (i) $T_{1/2} = 50$ s **(1)** (from graph)

(ii) $\lambda = \frac{\ln 2}{50}$ **(1)** = 0.014s^{-1} **(1)**

(iii) $N = \frac{A_0}{\lambda}$ **(1)** = $\frac{2.4\times10^5}{0.014}$ = $1.7(1)\times10^7$ **(1)** 5

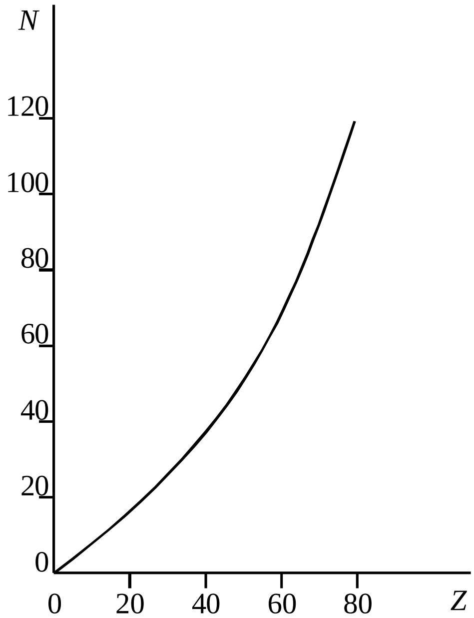
(b) (i) elapsed time = 50s = 1 half-life **(1)**
$N_{30} = N_0e^{-30\lambda}$ **(1)** = $1.71 \times 10^7\ \text{e}^{-30\times0.014} = 1.12 \times 10^7$ **(1)**
$\therefore$ no. decayed from t = 30s to t = 80s is $\frac{1.12\times10^7}{2}$ = $0{\cdot}56 \times 10^7$ **(1)**

[*alternative (b)(i)*
$N_{30} = \text{N}_0\text{e}^{-30\lambda}$ and $N_{80} = N_0\text{e}^{-80\lambda}$ **(1)**
give 1.12×10^7 **(1)** and 0.56×10^7 **(1)**
number decayed ($=1.12 \times 10^7 - 0.56 \times 10^7$) = 0.56×10^7 **(1)**]

(ii) energy released = $0.56 \times 10^7 \times 1.0 \times 10^{-12} = 5.6 \times 10^{-6}$ 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
α emission	–2	–2
β^- emission	+1	–1
β^+ 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^3
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

e.g. gradient = $\frac{300\times10^{-45}}{213}$ **(1)** (= 1.41×10^{-45} m^3)

r_0 (= gradient)$^{1/3}$ **(1)**

= $(1.41 \times 10^{-45})^{1/3}$ = $1.1(2) \times 10^{-15}$ m **(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	$R/10^{-15}$ 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
e.g. gradient = $\frac{6.72\times10^{-15}}{6.0}$ **(1)** = ($1.1(2) \times 10^{-45}$ m^3)
r_0 = gradient **(1)**
= $1.1(2) \times 10^{-15}$ m **(1)**
[or plot lnR against lnA...] 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 = $\frac{4}{3}\pi R^3 \rho$ **(1)**

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

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

= 2.8×10^{17} kgm^{-3} **(1)** 4

[12]

12. (a) (i) (inner) orbiting electron [or electron surrounding the nucleus] **(1)**
captured by a <u>proton</u> (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) $^{203}_{83}\text{Bi} \rightarrow {}^{203}_{82}\text{Pb} + {}_1\beta^+$ **(1)** + $\nu_{(e)}$ **(1)** (+Q) [allow $^{0}_{1}e^{+}$ for $_1\beta^+$] max 5

(b) (i) (use of $N = N_0 e^{-\lambda t}$ and $N \propto$ activity gives)
$290 = 1200 \exp(-\lambda \times 24 \times 60 \times 60)$ **(1)**
$\lambda = \frac{\ln(1200/290)}{24 \times 60 \times 60}$ **(1)** (= 1.64×10^{-5} s^{-1})

(ii) (use of $T_{½} = \ln 2/\lambda$ gives) $T_{½} = \frac{\ln 2}{1.64 \times 10^{-5}}$ **(1)**
= $4.2(3) \times 10^4$s **(1)** (= 11.(7) hr)

(use of $\lambda = 1.6 \times 10^{-5}$s^{-1} gives $T_{½} = 4.3 \times 10^4$s or 12 hr)

(iii) (use of $\frac{\Delta N}{\Delta t} = \lambda N$ gives) (–)1200 = (–)1.64×10^{-5} N **(1)**
$N = 7.3(2) \times 10^7$ (nuclei) **(1)**
(use of $\lambda = 1.6 \times 10^{-5}$ s^{-1} gives $N = 7.5 \times 10^7$ (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 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)**
$= 0.186$ u **(1)**
(if last term in Δm omitted or incorrect number of neutrons used in calculation, treat answer as C.E.)
energy released = 0.186 × 931 = 173 MeV **(1)**
(allow C.E. for Δm) 5

[8]

14. (a) (i) α (radiation) **(1)**

(ii) γ (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

(c) corrected count rate at 0.2 m (= 2550 – 50) = 2500 (c min^{-1}) **(1)**
corrected count rate at least distance (= 6000 – 50) = 5950 (c min^{-1}) **(1)**
use of $I = k\frac{I_o}{x^2}$ (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:
γ 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 β^- emitters and/or γ 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 5.5×10^5 Bq

plus correct 1st half-life (2.6 yrs, 2.75×10^5 Bq **(1)**

correct 2nd half-life (5.2 years, 1.4×10^5 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)**

$= 8.5 \times 10^{-9}$ (s^{-1}) **(1)**

(8.46×10^{-9} (s^{-1}))

(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 λ from (i))

(iii) (use of $N = N_0 e^{-\lambda t}$ and $A \propto N$ gives)

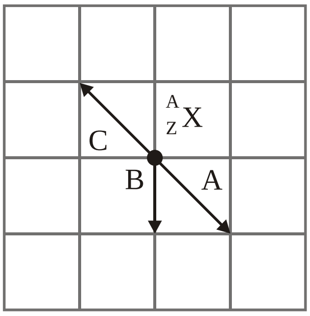
$$t\left(=\frac{\ln(A_0/A)}{\lambda}\right) = \frac{\ln(1.0 \times 10^5 / 0.75 \times 10^5}{8.5 \times 10^{-9}}$$ **(1)**

$= 3.4 \times 10^7$ (s) **(1)**

(allow C.E. for value of λ 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) 1.33×10^{-13} (J)
0.30×10^{-13} (J) for 3 correct values **(1)**
1.63×10^{-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 <u>with</u> 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) γ rays are more penetrating and are therefore more hazardous (to the internal organs of the body)

β^- 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 $^{210}_{82}\text{Pb}$; arrows must be consecutive; last arrow must end on $^{206}_{82}\text{Pb}$)
arrow showing the change for an α emission **(1)**
arrow showing the change for a β emission **(1)**
correct α and two β emissions in any order **(1)** 3

(b) (positron emission) $^{64}_{29}\text{Cu} \rightarrow {}^{64}_{28}\text{Ni} + \beta^+ + \nu_e$ (+Q) **(1)** **(1)**
(electron capture) $^{64}_{29}\text{Cu} + {}^{0}_{-1}e \rightarrow {}^{64}_{28}\text{Ni} + \nu_{(e)}$ (+Q) **(1)** **(1)** 4

(c) (the following examples may be included)

α particles **(1)**
coulomb/electrostatic/electromagnetic repulsion
[or K.E. converted to P.E. (as α 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 <u>by nucleus</u> **(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)**

$\lambda = \dfrac{\ln(107/81)}{600}$ **(1)**

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

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

$= 2.3(1) \times 10^5$ (nuclei) **(1)**

(allow C.E. for value of λ from (ii) 7

(b) α 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 α's directed away from body) **(1)**
[or reference to burning]

inside: more damage plus reason
(e.g. all α's absorbed living tissue will absorb α 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 $R^3/10^{-45}\text{m}^3$) **(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 α 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 α 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 → 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 α particles **(1)**
four β^- particles **(1)** 2

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

β^+
describe the changes to N (up by 1) and Z (down by 1)
[or allow p change to n]

α
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:
α particle has much more mass/momentum than β particle
α particle has twice as much charge as a β particle
α particle travels much slower than a β particle any **two (1) (1)** 2
QWC 1

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

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

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

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

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

= 0.90 K (or °C) **(1)**
(allow C.E. for incorrect value in (i)) 5

[7]

23. (a) R (= $r_0 A^{1/3}$) $= 1.3 \times 10^{-5} \times (238)^{1/3}$ **(1)**
$= 8.0(6) \times 10^{-15}$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)

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

$x = 0.095$ m **(1)**
(0.0949 m) 2

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

$\lambda = \frac{1n(100/0.85}{52}$ **(1)**

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

(d) it only emits γ rays **(1)**
relevant properties of γ 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)**

β^- 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.

Level	**Descriptor** an answer will be expected to meet most of the criteria in the level descriptor	**Mark range**
Good **3**	– answer supported by appropriate range of relevant points – good use of information or ideas about physics, going beyond those given in the question – argument well structured with minimal repetition or irrelevant points – accurate and clear expression of ideas with only minor errors of spelling, punctuation and grammar	**5-6**
Modest **2**	– answer partially supported by relevant points – good use of information or ideas about physics given in the question but limited beyond this – the argument shows some attempt at structure – the ideas are expressed with reasonable clarity but with a few errors of spelling, punctuation and grammar	**3-4**
Limited **1**	– valid points but not clearly linked to an argument structure – limited use of information or ideas about physics – unstructured – errors in spelling, punctuation and grammar or lack of fluency	**1-2**
0	– incorrect, inappropriate or no response	**0**

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 = $\frac{3.0 \times 10^{7}}{5}$ (= 6.0×10^{6}) **(1)**

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

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

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

new no. of gamma photons per sec per 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 cm^2 = 21(.2) × $2^{-6/12}$ **(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]