

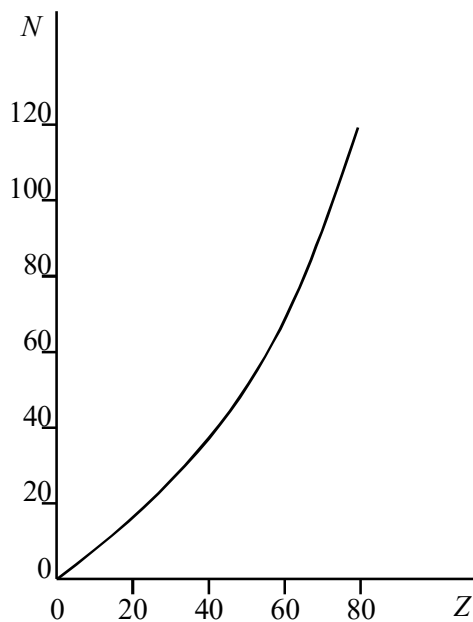
1. (a) (i) proton number 82 and nucleon number 214 **(1)**  
 (ii) Pb **(1)** 2
- (b) (i) kinetic energy [or electrostatic potential energy] **(1)**  
 (ii)  $\Delta m = \frac{E}{c^2}$  **(1)**  
 $= \frac{8.6 \times 10^{-13}}{(3 \times 10^8)^2} = 9.6 \times 10^{-30} \text{ kg}$  **(1)** 3

**[5]**

2.  $100\text{y} = 100 \times 365 \times 24 \times 3600 (= 3.15 \times 10^9 \text{ s})$  **(1)**  
 energy needed =  $3.15 \times 10^9 \times 300$  **(1)**  $\times 10$  **(1)**  $(= 9.46 \times 10^{12} \text{ J})$   
 number of disintegrations =  $\frac{9.46 \times 10^{12}}{3.2 \times 10^{-11}} (= 2.96 \times 10^{23})$  **(1)**  
 number of moles needed =  $\frac{2.96 \times 10^{23}}{6.02 \times 10^{23}}$   $(= 0.49)$  **(1)**  
 molar mass = 0.239kg **(1)**  
 mass needed =  $0.49 \times 0.239 = 0.117 \text{ kg}$  **(1)**

**[7]**

3. (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]**

4. (a) energy needed to separate **(1)**  
nucleus into constituent nucleons **(1)**

2

- (b) (i) mass defect =  $26 \times 1.00728 + 30 \times 1.00867$  **(1)**  
+  $26 \times 0.00055$  **(1)** –  $55.93493 = 0.529$ (u) **(1)**  
binding energy =  $0.529 \times 931 = 492$  (MeV) **(1)**  
binding energy per nucleon  $\frac{492}{56} = 8.8$  (MeV) **(1)**

- (ii) mass defect =  $0.529 \times 1.66 \times 10^{-27} = 8.8 \times 10^{-28}$  (kg) **(1)**

6

**[8]**

5. (a) (i)  $\lambda = \frac{0.693}{t_{1/2}} = \frac{0.693}{3420 \times 365 \times 24 \times 3600}$  **(1)**  
 $= 6.43 \times 10^{-12}$  ( $s^{-1}$ ) **(1)**

- (ii)  $N = \frac{1}{\lambda} \frac{dN}{dt} = \frac{450 \times 10^3}{6.43 \times 10^{-12}}$  **(1)**  
 $= 7.0 \times 10^{16}$  **(1)**

4

- (b) (i) pass through with no [or very small] deflection **(1)**  
 (ii) volume of nucleus  $\ll$  volume of atom (\*)  
 [or nucleus small and atom mostly empty space] (\*)  
 most of mass in nucleus (\*)  
 nucleus has positive charge (\*)  
 size of nucleus  $\ll$  separation (\*)  
 (\*) any two **(1) (1)**

3

[7]

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

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

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

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

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

max 6

[12]

7. (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)  ${}_{83}^{203}\text{Bi} \rightarrow {}_{82}^{203}\text{Pb} + {}_1\beta^+ \text{ (1)} + \nu_{(e)} \text{ (1)} (+Q)$  [allow  ${}^0_1e^+$  for  ${}_1\beta^+$ ] max 5
- (b) (i) (use of  $N = N_0e^{-\lambda t}$  and  $N \propto$  activity gives)  
 $290 = 1200 \exp(-\lambda \times 24 \times 60 \times 60) \text{ (1)}$   
 $\lambda = \frac{\ln(1200/290)}{24 \times 60 \times 60} \text{ (1)} (= 1.64 \times 10^{-5} \text{ s}^{-1})$
- (ii) (use of  $T_{1/2} = \ln 2 / \lambda$  gives)  $T_{1/2} = \frac{\ln 2}{1.64 \times 10^{-5}} \text{ (1)}$   
 $= 4.2(3) \times 10^4 \text{ s (1)} (= 11.(7) \text{ hr})$   
 (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)  $(-1200 = (-)1.64 \times 10^{-5} N \text{ (1)}$   
 $N = 7.3(2) \times 10^7 \text{ (nuclei) (1)}$   
 (use of  $\lambda = 1.6 \times 10^{-5} \text{ s}^{-1}$  gives  $N = 7.5 \times 10^7 \text{ (nuclei)}$ ) max 5
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

[10]

- (b) (i)  ${}_{94}^{239}\text{Pu} \rightarrow {}_{92}^{235}\text{U} + \alpha$  (1) (+Q)  
 (ii)  ${}_{92}^{235}\text{U} \rightarrow {}_{90}^{231}\text{Th} + \alpha$  (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) ( $R^3 = R_0^3 A$ )  
 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

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

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

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

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

$$\text{e.g. gradient} = \frac{6.72 \times 10^{-15}}{6.0} \quad \text{(1)} = (1.1(2) \times 10^{-45} \text{ m}^3)$$

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

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

[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)**

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

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

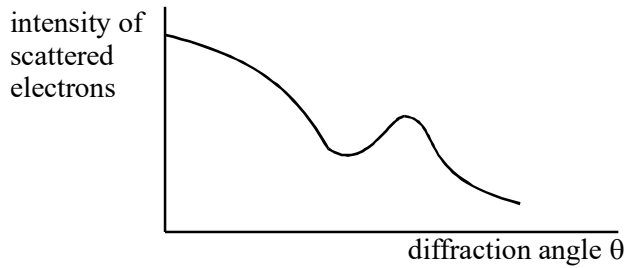
$$\left( \therefore \rho = \frac{3m}{4\pi R_0^3} \right) = \frac{3 \times 1.67 \times 10^{-27}}{4\pi \times (1.12 \times 10^{-15})^3} \quad \text{(1)}$$

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

4

[12]

10. (a)



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

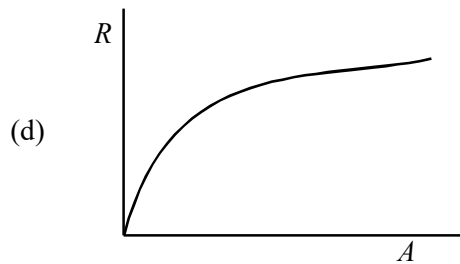
2

(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



correct curve (1)

1

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

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

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

3

[9]

11. (a) (i)  ${}_0^1\text{n} + {}_{92}^{235}\text{U} \rightarrow {}_{92}^{236}\text{U}$

(ii)  ${}_{92}^{236}\text{U} \rightarrow {}_{56}^{145}\text{Ba} + {}_{36}^{87}\text{Kr} + 4 {}_0^1\text{n}$  (1)

2

- (b) ( $\Delta m = m_u - m_{Ba} - m_{Kr} - 4m_n$ , electron masses balance)  
 $\Delta m = 236.04573 - 144.92694 - 86.91340 - 4 \times 1.00867$  (1)  
 $= 0.17071u$  (1)  
 $Q (= 0.17071 \times 931.3 \text{ MeV}) = 159 \text{ (MeV)}$  (1) 3

[5]

12. (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)]

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

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

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

- (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]

13. (a) (i) a neutron strikes the nucleus (1)  
 nucleus splits into two fragments (1)  
 (ii) some electrostatic  $E_p$  converted to  $E_k$  of fragments (1)  
 some electrostatic  $E_p$  used to overcome strong interaction (1)  
 some electrostatic  $E_p$  used to increase surface energy (1)  
 (iii) fission fragments repel and collide with other atoms in fuel rod (1)  
 high energy fission neutrons enter moderator  
 [or collide with moderator atoms] (1)  
 atoms gain  $E_k$  due to collisions (and vibrate more) (1)  
 temperature depends on the average  $E_k$  of (vibrating) atoms (1)  
 a chain reaction occurs (1) max 8

- (b) energy from fuel per year at 100% efficiency



$$= 1600(\text{MW}) \times 3.2 \times 10^7 \text{ s} \approx 5.0 \times 10^{16} \text{ (J) (1)}$$

energy supplied from fuel per year at 25% efficiency

$$\approx 4 \times 5.0 \times 10^{16} \approx 2.0 \times 10^{17} \text{ (J) (1)}$$

energy released per kilogram of fuel

$$= 200 \times 1.6 \times 10^{-13} \times 6.0 \times 10^{23} \times \frac{1}{0.238} \text{ (1)} \times 0.03 \approx 2.4 \times 10^{12} \text{ (J) (1)}$$

$$\text{mass of fuel needed per year} = \frac{2.0 \times 10^{17}}{2.4 \times 10^{12}} \approx 8 \times 10^4 \text{ kg (1)}$$

5

[13]

14. (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 (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

$$[\text{or } p \rightarrow n + \beta^+ (+ \nu_e + Q)] \text{ (1)}$$

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]

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

1

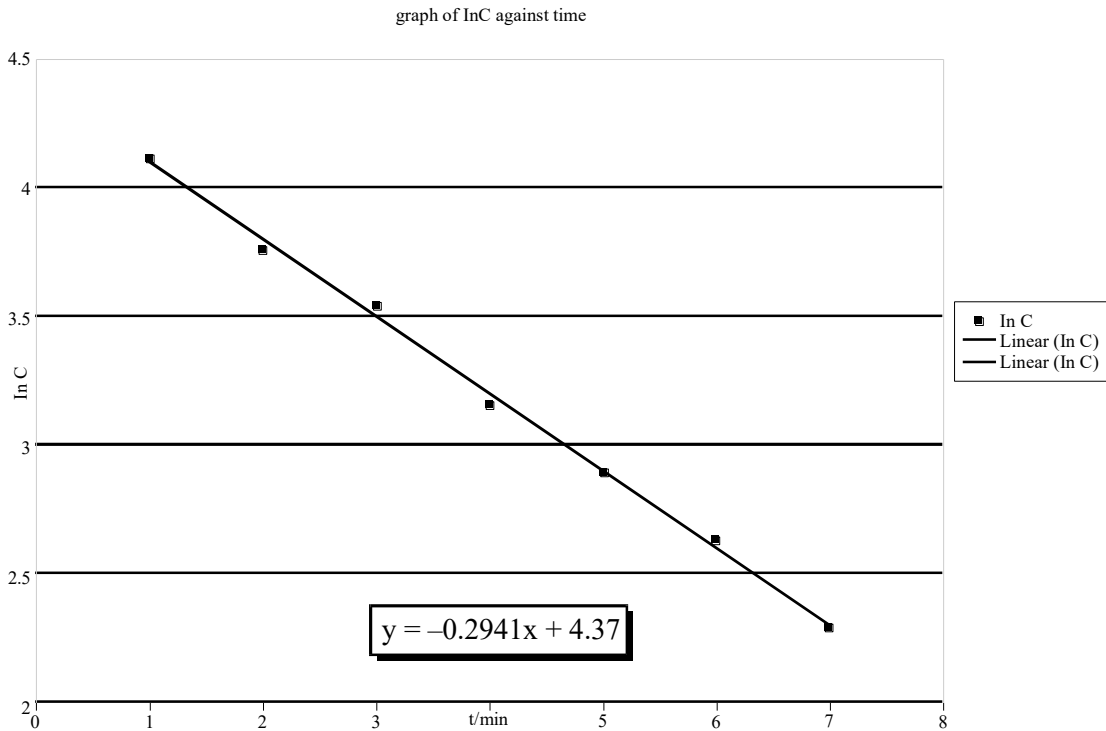
- (b)

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<sup>-1</sup>) (min<sup>-1</sup>)

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)

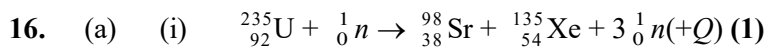
max 2

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

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

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

4

**[16]**

(ii) three correct positions to within  $\pm 2$  on x-axis **(1) (1)**  
(one mark if two correct)

(iii) *estimate of energy released:*

$$\text{binding energy of U-235 nucleus} = (235 \times 7.5)$$

$$= 1763(\pm 15) \text{ (MeV)} \quad (1)$$

$$\text{binding energy of Sr-98} = (98 \times 8.6)$$

$$= 843(\pm 15) \text{ (MeV)} \quad (1)$$

$$\text{binding energy of Xe-135} = (135 \times 8.4)$$

$$= 1134(\pm 15) \text{ (MeV)} \quad (1)$$

$$\text{binding energy released} = 1134 + 843 - 1763$$

$$= 214 \text{ MeV} \quad (1)$$

$$(\pm 40 \text{ MeV})$$

max 6

(b) (i) 235g of U-235 releases  $6 \times 10^{23} \times 214 \times 1.6 \times 10^{-13} \text{ J}$   
 $= 2.1 \times 10^{13} \text{ (J)} \quad (1)$

1.0 kg of uranium containing 3% U-235 contains  
 30g of U-235 **(1)**

$$\text{energy from 1.0kg of uranium} = \frac{2.1 \times 10^{13} \times 30}{235}$$

$$= 2.6 \times 10^{12} \text{ J} \quad [1.6 \times 10^{25} \text{ MeV}] \quad (1)$$

- (ii) *advantage:*  
 less mass of fuel used **(1)** because more energy per kilogram **(1)**  
 [alternative: less harm to environment **(1)** because does not  
 generate greenhouse gases **(1)**  
 or any statement **(1)** argued **(1)**]  
*disadvantage:*  
 hazardous waste **(1)** because fission products are radioactive **(1)**  
 [alternative: long term responsibility **(1)** because waste needs  
 to be stored for many years **(1)**  
 or any statement **(1)** argued **(1)**]

max 6

**[12]**

17. (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)**  
 loss of ke. [or  $1.33 \times 10^{-12}$ ] =  $\frac{Qq}{4\pi\epsilon_0 R}$  **(1)**  $\left( = \frac{2Ze^2}{4\pi\epsilon_0 R} \right)$

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

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

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]**

18. (a) (i) proportion of U-235 is greater than in natural uranium **(1)**  
 (ii) induced fission more probable with U-235 than with U-238 **(1)**

2

- (b) (i) for steady rate of fission, one neutron per fission required to go on to produce further fission **(1)**  
 each fission produces two or three neutrons on average **(1)**  
 some neutrons escape [or some absorbed by U-238 without fission] **(1)**  
 control rods absorb sufficient neutrons (to maintain steady rate of fission) **(1)**
- (ii) neutrons need to pass through a moderator **(1)**  
 to slow them (in order to cause further fissions or prevent U-238 absorbing them) **(1)**  
 neutrons that leave the fuel rod (and pass through the moderator) are unlikely to re-enter the same fuel rod **(1)**  
 makes it easier to replace the fuel in stages **(1)** max 5

[7]

19. (a) (i) most alpha particles undeflected **(1)**  
 some through small angles **(1)**  
 (very) small (but significant) number deflected through  $> 90^\circ$  **(1)** max 2

- (b) atom mostly empty space **(1)**  
 positive charge concentrated **(1)**  
 in a volume much less than total volume [or radius] **(1)** max 2

[4]

20. (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]