Nuclear Physics

Mark Scheme 3

Level	International A Level
Subject	Physics
Exam Board	CIE
Topic	Particle & Nuclear Physics
Sub Topic	Nuclear Physics
Paper Type	Theory
Booklet	Mark Scheme 3

Time Allowed: **81 minutes**

Score: **/67**

Percentage: **/100**

A*	A	B	C	D	E	U
>85%	'77.5%	70%	62.5%	57.5%	45%	<45%

1 **(a)** probability of decay (of a nucleus) / fraction of number of nuclei in sample that decay M1
per unit time A1 [2]
(*allow λ =(dN / dt) / N with symbols explained – (M1), (A1)*)

(b) **(i)** number $= (1.2 \times 6.02 \times 10^{23}) / 235$ C1
$= 3.1 \times 10^{21}$ A1 [2]

(ii) $N = N_0\, e^{-\lambda t}$
negligible activity from the krypton B1
for barium, $N = (3.1 \times 10^{21}) \exp(-6.4 \times 10^{-4} \times 3600)$
$= 3.1 \times 10^{20}$ C1
activity $= \lambda N$
$= 6.4 \times 10^{-4} \times 3.1 \times 10^{20}$ C1
$= 2.0 \times 10^{17}$ Bq A1 [4]

2 **(a** two (light) nuclei combine M1
to form a more massive nucleus A1 [2]

(b) **(** Δm $= (2.01410\,u + 1.00728\,u) - 3.01605\,u$
$= 5.33 \times 10^{-3}\,u$ C1
energy $= c^2 \times \Delta m$ C1
$= 5.33 \times 10^{-3} \times 1.66 \times 10^{-27} \times (3.00 \times 10^8)^2$
$= 8.0 \times 10^{-13}\,J$ A1 [3]

(ii) speed/kinetic energy of proton and deuterium must be very large B1
so that the nuclei can overcome electrostatic repulsion B1 [2]

3 **(a** energy is given out / released on formation of the α-particle (or reverse argument) M1
either $E = mc^2$ so mass is less
or reference to mass-energy equivalence A1 [2]

(b) mass change = 18.00567 u – 18.00641 u C1
$= 7.4 \times 10^{-4}$ u *(sign not required)* A1 [2]

(ii) energy $= c^2\Delta m$
$= (3.0 \times 10^8)^2 \times 7.4 \times 10^{-4} \times 1.66 \times 10^{-27}$ C1
$= 1.1 \times 10^{-13}$ J A1 [2]
(*allow use of* u = 1.67×10^{-27} kg)
(*allow method based on* 1u *equivalent to* 930 MeV *to* 933 MeV)

(iii) *either* mass of products greater than mass of reactants M1
this mass/energy provided as kinetic energy of the helium-4 nucleus A1
or both nuclei positively charged (M1)
energy required to overcome electrostatic repulsion (A1) [2]

4 **(a (i)** $x = 2$ A1 [

(ii) *either* beta particle *or* electron B1 [1]

(b) (mass of separate nucleons = {(92 × 1.007) + (143 × 1.009)} u C1
= 236.931 u C1
binding energy = 236.931 u – 235.123 u
= 1.808 u A1 [3]

(ii) $E = mc^2$ C1
energy = $1.808 \times 1.66 \times 10^{-27} \times (3.0 \times 10^8)^2$
= 2.7×10^{-10} J C
binding energy per nucleon = $(2.7 \times 10^{-10}) / (235 \times 1.6 \times 10^{-13})$ M
= 7.18 MeV [3]

(c) energy released = (95 × 8.09) + (139 × 7.92) – (235 × 7.18) C1
= 1869.43 – 1687.3
= 182 MeV A1 [2]
(*allow calculation using mass difference between products and reactants*)

5 **(a (i)** *either* probability of decay (of a nucleus) M1
per unit time A1 [2]
or $\lambda = (–)(\mathrm{d}N/\mathrm{d}t) / N$ (M1)
$(–)\mathrm{d}N/\mathrm{d}t$ and N explained (A1)

(ii) in time $t_{½}$, number of nuclei changes from N_0 to $½N_0$ B1
$½ = \exp(–\lambda t_{½})$ *or* $2 = \exp(\lambda t_{½})$ B1
$\ln(½) = –\lambda t_{½}$ and $\ln(½) = –0.693$ *or* $\ln 2 = \lambda t_{½}$ and $\ln 2 = 0.693$ B1
$0.693 = \lambda t_{½}$ A0 [3]

(b) $228 = 538 \exp(–8\lambda)$ C
$\lambda = 0.107$ (hours^{-1}) C1
$t_{½} = 6.5$ hours *(do not allow 3 or more SF)* A1 [3]

(c) e.g. random nature of decay
background radiation
daughter product is radioactive
(any two sensible suggestions, 1 each) B2 [2]

6 **(a** <u>nuclei</u> having same number of protons/proton (atomic) number B1
different numbers of neutrons/neutron number B1 [2]
(allow second mark for nucleons/nucleon number/mass number/atomic mass if made clear that same number of protons/proton number)

(b) probability of decay per unit time is the decay constant C1
$\lambda = \ln 2 / t_{½}$
$= 0.693 / (52 \times 24 \times 3600)$ C1
$= 1.54 \times 10^{-7}\,s^{-1}$ A1 [3]

(c) **(** $A = A_0 \exp(-\lambda t)$
$7.4 \times 10^6 = A_0 \exp(-1.54 \times 10^{-7} \times 21 \times 24 \times 3600)$ C1
$A_0 = 9.8 \times 10^6$ Bq A1 [2]
(*alternative method uses 21 days as 0.404 half-lives*)

(ii) $A = \lambda N$ and mass $= N \times 89 / N_A$ C1
mass $= (9.8 \times 10^6 \times 89) / (1.54 \times 10^{-7} \times 6.02 \times 10^{23})$
$= 9.4 \times 10^{-9}$ g A1 [2]

7 **(a)** **(i)** time for initial number of nuclei/activity M1
to reduce to one half of its initial value A1 [2]

(ii) $\lambda = \ln 2/(24.8 \times 24 \times 3600)$ M1
$= 3.23 \times 10^{-7}\ s^{-1}$ A0 [1]

(b) **(i)** $A = \lambda N$ C1
$3.76 \times 10^6 = 3.23 \times 10^{-7} \times N$
$N = 1.15 \times 10^{13}$ A1 [2]

(ii) $N = N_0\, e^{-\lambda t}$
$= 1.15 \times 10^{13} \times \exp(-\{\ln 2 \times 30\}/24.8)$ C1
$= 4.97 \times 10^{12}$ A1 [2]

(c) ratio $= (4.97 \times 10^{12})/(1.15 \times 10^{13} - 4.97 \times 10^{12})$ C1
$= 0.76$ A1 [2]

8	**(a**	**(i)**	probability of decay (of a nucleus)	M1	
			<u>per</u> unit time	A1	[2]
		(ii)	$\lambda t_{½} = \ln 2$		
			$\lambda = \ln 2/(3.82 \times 24 \times 3600)$	M1	
			$= 2.1 \times 10^{-6}\ s^{-1}$	A0	[1]
	(b)		$A = \lambda N$	C1	
			$200 = 2.1 \times 10^{-6} \times N$	C1	
			$N = 9.5 \times 10^{7}$		
			ratio $= (2.5 \times 10^{25})/(9.5 \times 10^{7})$		
			$= 2.6 \times 10^{17}$	A1	[3]