CAMBRIDGE INTERNATIONAL AS & A LEVEL PHYSICS · 9702

PHYSICS



MARK SCHEME

11 PARTICLE PHYSICS

SCORE	PERCENTAGE
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Paper 1 Multiple Choice Answers: Particle Physics

Question	Paper	Q. No.	Answer
1309	9702_m20_qp_12	38	D
1310	9702_s20_qp_11	39	B
1311	9702_s20_qp_12	39	B
1312	9702_s20_qp_13	39	A
1313	9702_m19_qp_12	39	D
1314	9702_m19_qp_12	40	D
1315	9702_s19_qp_11	39	A
1316	9702_s19_qp_12	38	C
1317	9702_s19_qp_13	39	A
1318	9702_w19_qp_11	39	B
1319	9702_w19_qp_12	38	B
1320	9702_w19_qp_12	39	C
1321	9702_w19_qp_13	39	D
1322	9702_m18_qp_12	39	D
1323	9702_s18_qp_11	40	D
1324	9702_s18_qp_12	38	C
1325	9702_s18_qp_12	39	B
1326	9702_s18_qp_13	39	C
1327	9702_w18_qp_11	39	D
1328	9702_w18_qp_12	39	C
1329	9702_w18_qp_13	38	C
1330	9702_w18_qp_13	39	A
1331	9702_m17_qp_12	38	C
1332	9702_s17_qp_11	38	A
1333	9702_s17_qp_11	39	B
1334	9702_s17_qp_12	38	A
1335	9702_s17_qp_12	39	B
1336	9702_s17_qp_13	37	A
1337	9702_s17_qp_13	38	D
1338	9702_s17_qp_13	39	A
1339	9702_w17_qp_11	39	B
1340	9702_w17_qp_12	39	A
1341	9702_w17_qp_13	39	C
1342	9702_m16_qp_12	38	A
1343	9702_m16_qp_12	39	C
1344	9702_m16_qp_12	40	B
1345	9702_s16_qp_11	39	D
1346	9702_s16_qp_11	40	A
1347	9702_s16_qp_12	38	C
1348	9702_s16_qp_13	38	D
1349	9702_s16_qp_13	39	B
1350	9702_w16_qp_11	39	C
1351	9702_w16_qp_11	40	B
1352	9702_w16_qp_12	39	C
1353	9702_w16_qp_13	39	C
1354	9702_w16_qp_13	40	B

Paper 1 Multiple Choice Answers: Particle Physics (continued)

Question	Paper	Q. No.	Answer
1355	9702_s15_qp_11	39	C
1356	9702_s15_qp_11	40	B
1357	9702_s15_qp_12	38	A
1358	9702_s15_qp_12	39	C
1359	9702_s15_qp_12	40	C
1360	9702_s15_qp_13	38	D
1361	9702_s15_qp_13	39	A
1362	9702_s15_qp_13	40	C
1363	9702_m20_qp_12	39	D
1364	9702_m20_qp_12	40	C
1365	9702_s20_qp_11	40	C
1366	9702_s20_qp_12	40	A
1367	9702_s20_qp_13	40	C
1368	9702_s19_qp_11	40	D
1369	9702_s19_qp_12	39	C
1370	9702_s19_qp_12	40	D
1371	9702_s19_qp_13	40	A
1372	9702_w19_qp_11	40	D
1373	9702_w19_qp_12	40	B
1374	9702_w19_qp_13	40	A
1375	9702_m18_qp_12	40	B
1376	9702_s18_qp_11	38	C
1377	9702_s18_qp_11	39	D
1378	9702_s18_qp_12	40	B
1379	9702_s18_qp_13	40	A
1380	9702_w18_qp_11	40	B
1381	9702_w18_qp_12	40	A
1382	9702_w18_qp_13	40	A
1383	9702_m17_qp_12	39	B
1384	9702_m17_qp_12	40	C
1385	9702_s17_qp_11	40	C
1386	9702_s17_qp_12	40	A
1387	9702_s17_qp_13	40	A
1388	9702_w17_qp_11	40	A
1389	9702_w17_qp_12	40	C
1390	9702_w17_qp_13	40	B
1391	9702_s16_qp_11	38	A
1392	9702_s16_qp_12	39	B
1393	9702_s16_qp_12	40	D
1394	9702_s16_qp_13	40	C
1395	9702_w16_qp_11	38	A
1396	9702_w16_qp_12	40	A
1397	9702_w16_qp_13	38	A

249. 9702_w15_qp_22 Q: 5

(a) (i) $I = V/R$ C1

(= 240 / 1500 =) 0.16 A A1 [2]

(ii) I_2 = 0.40 – 0.16 (= 0.24) C1

0.24 (350 + R) = 240

R = 650 Ω A1 [2]

(iii) power = IV **or** I^2R **or** V^2/R C1

ratio = (84 × 0.24) / (88 × 0.16)
or [$(0.24)^2$ × 350] / [$(0.16)^2$ × 550]
or (84^2/350) / (88^2/550)
or 20.16 / 14.08

= 1.4(3) A1 [2]

(b) (i) p.d. across 350 Ω resistor = 0.24 × 350
or p.d. across 550 Ω resistor = 0.16 × 550 C1

V_{350} = 84 (V) and V_{550} = 88 (V) gives V_{AB} = 4.0 V
or V_{950} = 152 (V) and V_R = 156 V gives V_{AB} = 4.0 V A1 [2]

(ii) p.d. across R increases **or** potential at B increases **or** V_{350} decreases hence V_{AB} increases B1 [1]

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250. 9702_s20_qp_21 Q: 6

	Answer	Mark
(a)(i)	$E = \Delta V / \Delta d$	C1
	E = (180 + 120) / (2.0 × 10^{-2}) = 1.5 × 10^4 N C^{-1}	A1
(a)(ii)	vertically downwards	B1
(b)(i)	number of protons = 92	A1
	number of neutrons = 146	A1
	number of electrons = 90	A1
(b)(ii)	$F = EQ$	C1
	= 1.5 × 10^4 × 2 × 1.60 × 10^{-19} = 4.8 × 10^{-15} N	A1
(b)(iii)	number of α-particles = 2	A1
	number of β^- particles = 2	A1

251. 9702_w20_qp_23 Q: 7

	Answer	Mark
(a)(i)	electric field strength = V / d	B1
(a)(ii)	force = Vq / d	B1
(a)(iii)	kinetic energy = Vq	B1
(b)(i)	no change	B1
(b)(ii)	no change	B1
(c)(i)	nucleon number = 14 **and** proton number = 7	A1
(c)(ii)	(electron) antineutrino	B1

252. 9702_w19_qp_22 Q: 7

	Answer	Mark
(a)	number of protons = 92	A1
	number of neutrons = 142	A1
(b)	5.6 MeV = $5.6 \times 1.60 \times 10^{-19} \times 10^{6}$ (= 8.96×10^{-13} J)	C1
	number = $0.15 / (5.6 \times 1.60 \times 10^{-13})$ = 1.7×10^{11}	A1
	or	
	0.15 W = $0.15 / (1.60 \times 10^{-19} \times 10^{6})$ (= 9.38×10^{11} MeV s^{-1})	(C1)
	number = $9.38 \times 10^{11} / 5.6$ = 1.7×10^{11}	(A1)

253. 9702_w19_qp_23 Q: 7

	Answer	Mark
(a)	number of protons = 95	A1
	number of neutrons = 146	A1
(b)	Np/neptunium (nucleus) has <u>kinetic</u> energy **or** gamma/γ-radiation produced	B1
(c)(i)	$I = NQ / t$	C1
	$I = (6.9 \times 10^{11} \times 2 \times 1.60 \times 10^{-19}) / 30$ = 7.4×10^{-9} A	A1
(c)(ii)	$P = (6.9 \times 10^{11} \times 5.5 \times 10^{6} \times 1.60 \times 10^{-19}) / 30$	C1
	= 0.020 W	A1

254. 9702_m18_qp_22 Q: 6

	Answer	Mark
(a)	–1 / decreases by 1	A1
(b)	$I = Q/t$ or Ne/t	C1
	$= (9.8\times10^{10} \times 1.6\times10^{-19}) / (2.0 \times 60)$ $= 1.3 \times 10^{-10}$ (A)	C1
	= 130 pA	A1
(c)	antineutrino(s) (emitted) / other particle(s) (emitted)	C1
	energy / momentum shared with antineutrino(s)	A1

255. 9702_w18_qp_21 Q: 5

	Answer	Mark
(a)	region (of space) where a force acts on a (stationary) charge	B1
(b)	$E = F/Q$	B1
	$F = ma$ **and** (so) $a = \frac{Eq}{m}$	A1
(c)(i)	protons = 96	A1
	neutrons = 148	A1
(c)(ii)	mass-energy is conserved/mass change is 'seen' as energy	B1
	energy released as gamma (radiation)/KE of α/KE of Pu	B1
(c)(iii)	ratio $= \frac{2}{4} \times \frac{240}{94}$ **or** ratio $= \frac{2\times1.60\times10^{-19}}{4\times1.66\times10^{-27}} \times \frac{240\times1.66\times10^{-27}}{94\times1.60\times10^{-19}}$	C1
	ratio = 1.3	A1

256. 9702_w18_qp_23 Q: 5

	Answer	Mark
(a)	$E = F/Q$	M1
	$F = ma$ **and** (so) $q/m = a/E$	A1
(b)	$m = (4 \times 1.60 \times 10^{-19} \times 3.5 \times 10^{4}) / 1.5 \times 10^{12}$ (= 1.49×10^{-26} kg)	B1
	$= 1.49 \times 10^{-26} / 1.66 \times 10^{-27}$ = 9.0 (u)	A1
(c)	protons: 4 **and** neutrons: 5	A1
(d)(i)	nuclei have the same charge and so same (magnitudes of) force	B1
(d)(ii)	nuclei have different masses and same force and so different (magnitudes of) acceleration	B1

257. 9702_m17_qp_22 Q: 7

	Answer	Mark
(a)	number of protons = 83 and number of neutrons = 129	A1
(b)	$\lambda = 3.8 \times 10^{-12}$	C1
	$f = 3.0 \times 10^{8} / 3.8 \times 10^{-12}$	C1
	$f = 7.9 \times 10^{19}$ (7.89×10^{19}) Hz	A1
(c)	use an electric field (at an angle to the beam)	M1
	α is deflected and γ is undeflected	A1
(d)	*either*	
	energy $= 9.3 \times 10^{-13} / 1.8 \times 10^{5}$ ($= 5.17 \times 10^{-18}$ J)	C1
	$= 5.17 \times 10^{-18} / 1.6 \times 10^{-19}$ $= 32$ (32.3) eV	A1
	or	
	energy $= 9.3 \times 10^{-13} / 1.6 \times 10^{-19}$ ($= 5.81 \times 10^{6}$ eV)	(C1)
	$= 5.81 \times 10^{6} / 1.8 \times 10^{5}$ $= 32$ (32.3) eV	(A1)

258. 9702_w17_qp_23 Q: 7

	Answer	Mark
(a)	nucleons = 23	B1
	neutrons = 11	B1
(b)	similarity: same (rest) mass **or** equal (magnitude of) charge	B1
	difference: opposite (sign of) charge **or** one is matter and one is antimatter **or** one is an electron and one is an antielectron	B1

259. 9702_s15_qp_22 Q: 7

(a) 92 protons and 143 neutrons B1 [1]

(b)

	value
a	1
b	0
c	141
d	55

(a and b both required) B1
B1
B1 [3]

(c) kinetic energy (of products) or gamma/γ (radiation or photon) B1 [1]

(d) (total) mass on left-hand side/reactants is greater than (total) mass on right-hand side/products M1

difference in mass is (converted to) energy A1 [2]

260. 9702_s15_qp_23 Q: 7

(a) (i) (rate of decay) not affected by any external factors **or** changes in temperature and pressure etc. B1 [1]

(ii) two protons and two neutrons B1 [1]

(b) (i) (total) mass before decay/on left-hand side is greater than (total) mass on right-hand side/after the decay M1

the difference in mass is released as kinetic energy of the products A1 [2]

(may also be some γ radiation) (to conserve mass-energy)

(ii) $(6.2 \times 10^6 \times 1.6 \times 10^{-19} =) 9.9(2) \times 10^{-13}$ J A1 [1]

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261. 9702_w15_qp_21 Q: 7

(a) (i) curved path towards negative (–) plate (right-hand side) B1 [1]

(ii) range of α-particle is only few cm in air/loss of energy of the α-particles due to collision with air molecules/ionisation of the air molecules B1 [1]

(iii) $V = E \times d$ C1

$= 140 \times 10^6 \times 12 \times 10^{-3} = 1.7\ (1.68)$ MV A1 [2]

(b) β have opposite charge to α therefore deflection in opposite direction B1

β has a range of velocities/energies hence number of different deflections B1

β have less mass or q/m is larger hence deflection is greater
or
β with (very) high speed (may) have less deflection B1 [3]

(c)

emitted particle	change in Z	change in A
α-particle	–2	–4
β-particle	+1	0

A1 [1]

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262. 9702_w15_qp_22 Q: 8

(a) result: majority / most (of the α-particles) went straight through/were deviated by small angles — M1

conclusion: most of the atom is (empty) space **or** size/volume of nucleus very small compared with atom — A1

result: a small proportion were deflected through large angles or >90° or came straight back — M1

conclusion: the mass or majority of mass is in a (very) small charged volume/region/nucleus — A1 [4]

(b) $\rho = m / V$ — C1

mass of atom and mass of nucleus (approx.) equal stated **or** cancelled **or** values given e.g. 63 u or $63 \times 1.66 \times 10^{-27}$ — C1

ratio $= (r_A)^3 / (r_N)^3 = (1.15 \times 10^{-10})^3 / (1.4 \times 10^{-14})^3$
or
ratio $= (d_A)^3 / (d_N)^3 = (2.3 \times 10^{-10})^3 / (2.8 \times 10^{-14})^3$
$= 5.5 \times 10^{11}$ — A1 [3]

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263. 9702_w15_qp_23 Q: 8

(a) mass-energy
proton number or charge
nucleon number — B2 [2]

(b) **(i)** $E_k = \frac{1}{2} mv^2$ and $p = mv$ with working leading to

[via $E_k = \frac{1}{2} m^2 v^2 / m$ or $\frac{1}{2} m (p/m)^2$]
to $E_k = \dfrac{p^2}{2m}$ — B1 [1]

(ii) $p = (2E_k m)^{\frac{1}{2}}$ hence $(2[E_k m]_\alpha)^{\frac{1}{2}} = (2[E_k m]_{Th})^{\frac{1}{2}}$ — C1

$2 \times [E_k]_{Th} \times 234 = 2 \times 6.69 \times 10^{-13} \times 4$ — C1

$[E_k]_{Th} = 1.14 \times 10^{-14}$ J
$= 71(.5)$ keV — A1

or

calculation of speed of α-particle $= 1.42 \times 10^7$ m s^{-1}
calculation of momentum of α-particle/nucleus $= 9.43 \times 10^{-20}$ N s — (C1)

$[E_k]_{Th} = 1.14 \times 10^{-14}$ J — (C1)
$= 71(.5)$ keV — (A1) [3]

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264. 9702_m20_qp_22 Q: 7

	Answer	Mark
(a)	made up of quarks (so) not a fundamental particle	B1
(b)(i)	beta plus / β^+ (particle)	B1
	(electron) neutrino / $\nu_{(e)}$	B1
(b)(ii)	kinetic energy of nucleus	B1
	gamma / γ radiation	B1

265. 9702_s20_qp_22 Q: 7

	Answer	Mark
(a)(i)	P = 0 **and** Q = 39	A1
	R = (+)1 **and** S = 20	A1
(a)(ii)	weak (nuclear force/interaction)	B1
(b)	charge of quark(s) = (+) 2*e* / 3	B1
	up/u (quarks)	B1

266. 9702_s20_qp_23 Q: 7

	Answer	Mark
(a)(i)	$E = V / d$ **or** $E = F / Q$	C1
	$F = (450 \times 1.60 \times 10^{-19}) / 6.0 \times 10^{-3}$	C1
	$= 1.2 \times 10^{-14}$ N	A1
	direction: vertically downwards	B1

	Answer	Mark
(a)(ii)	work done = Fs **or** Fd **or** EQd	C1
	$= (-)1.2 \times 10^{-14} \times 6.0 \times 10^{-3}$	A1
	$= (-)7.2 \times 10^{-17}$ J	
	or	
	work done = VQ	(C1)
	$= (-)450 \times 1.60 \times 10^{-19}$	(A1)
	$= (-)7.2 \times 10^{-17}$ J	
(b)	$E = \frac{1}{2}mv^2$	C1
	$3.4 \times 10^{-16} = \frac{1}{2} \times 9.11 \times 10^{-31} \times v^2$	A1
	$v = 2.7 \times 10^7$ m s^{-1}	
(c)(i)	${}^{1}_{1}\mathrm{p}$	A1
	${}^{0}_{0}\overline{\nu}_{(e)}$	A1
(c)(ii)	**1.** hadrons	B1
	2. leptons	B1

267. 9702_w20_qp_21 Q: 8

	Answer	Mark
(a)	similarity: same/equal mass **or** same/equal (magnitude of) charge **or** both fundamental (particles)	B1
	difference: opposite (sign of) charge **or** one is matter and the other is antimatter	B1
(b)(i)	number of protons = 13 **and** number of neutrons = 12	A1
(b)(ii)	(charge =) $13 \times 1.60 \times 10^{-19}$ (C) = 2.1×10^{-18} (C)	A1
(c)	force = $11 \times 10^3 \times 2.1 \times 10^{-18}$	C1
	work done = $11 \times 10^3 \times 2.1 \times 10^{-18} \times 0.04$	C1
	= 9.2×10^{-16} J	A1

268. 9702_w20_qp_22 Q: 7

	Answer	Mark
(a)	similarity: same/equal mass **or** same/equal (magnitude of) charge **or** both fundamental (particles)	B1
	difference: opposite (sign of) charge **or** one is matter and the other is antimatter	B1
(b)(i)	arrow points to the right	B1
(b)(ii)	(electric) field strength increases **or** (electric) force increases	B1
	acceleration increases	B1
(b)(iii)	force (on α-particle) has twice the magnitude (of force on electron)	B1
	force (on α-particle) is in opposite direction (to force on electron)	B1

269. 9702_m19_qp_22 Q: 7

	Answer	Mark
(a)(i)	alpha, neutron and proton	B1
(a)(ii)	neutron	B1
(a)(iii)	beta plus or β^+	B1
(b)	$\bar{d}$ has charge (+)⅓ e	C1
	(so) other quark has charge = e – ⅓ e = (+)⅔ e	M1
	other quark is an up / u	A1

270. 9702_s19_qp_21 Q: 7

	Answer	Mark
(a)	nucleus is charged	B1
	the mass is concentrated in (very small) nucleus **or** the majority of the mass is in (very small) nucleus	B1
(b)(i)	$-(1/3)e$	B1
(b)(ii)	$2q - (1/3)e = e$ so $q = (2/3)e$	M1
	up / u (quarks) (*allow charm or top quarks*)	A1

271. 9702_s19_qp_22 Q: 6

	Answer	Mark
(a)	path/direction in which a (free) positive charge will move	B1
(b)	(lines) closer together in Y/further apart in X	B1
(c)(i)	$a = Eq / m$ **or** $F = Eq$ **and** $F = ma$	C1
	ratio $= (1e / 0.15\text{ u}) \times (4\text{ u} / 2e)$ **or** $1 / 0.15 \times 4 / 2$	C1
	ratio = 13	A1
(c)(ii)	down quark charge is $-(1/3)e$	C1
	$-(1/3)e + q = -1e$ so $q = -(2/3)e$	A1
	$(-(2/3)e$ is) anti-up / $\bar{u}$ (quark) (*allow charm or top antiquark*)	B1

272. 9702_s19_qp_23 Q: 7

	Answer	Mark
(a)	beta/β	B1
(b)	alpha/α	B1
(c)	gamma/γ	B1
(d)	beta/β	B1

273. 9702_w19_qp_21 Q: 7

	Answer	Mark
(a)(i)	proton number = 17 **and** nucleon number = 35	A1
(a)(ii)	(electron) neutrino	B1
(b)	d/down (quark charge) is $-\frac{1}{3}(e)$ **or** two d/down (quark charges) is $-\frac{2}{3}(e)$ **or** s/strange (quark charge) is $-\frac{1}{3}(e)$	C1
	charge $= -\frac{1}{3}(e) - \frac{1}{3}(e) - \frac{1}{3}(e)$ $= -1(e)$	A1

274. 9702_s18_qp_21 Q: 7

	Answer	Mark
(a)	arrow pointing vertically down the page	B1
(b)	$E = ½mv^2$	C1
	$E = 460 \times 1.60 \times 10^{-19}$ (= 7.36×10^{-17} (J))	C1
	$v = [(2 \times 460 \times 1.60 \times 10^{-19})/(9.11 \times 10^{-31})]^{½}$ $= 1.3 \times 10^{7}\,\text{m s}^{-1}$	A1
(c)	β^- particles have range of/different/various speeds/velocities/momenta/energies	M1
	so they follow different paths	A1

275. 9702_s18_qp_22 Q: 7

	Answer	Mark
(a)	circle(s) drawn only around β^- and $\bar{\nu}$ symbols	B1
(b)	(electron) antineutrino	B1
(c)	kinetic (energy)	B1
(d)	Y has one more proton (and one less neutron)/X has one less proton (and one more neutron) **or** Y has more protons (and fewer neutrons)/X has fewer protons (and more neutrons) **or** a neutron changes to a proton **or** the number of protons increases	M1
	(so) not isotopes	A1
(e)	up down down changes to up up down **or** udd → uud **or** down changes to up **or** d → u	B1

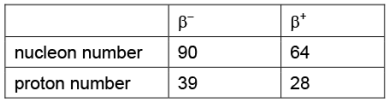
276. 9702_s18_qp_23 Q: 7

	Answer	Mark
(a)(i)	Q plotted at (82, 210)	A1
(a)(ii)	R plotted at (83, 210)	A1
(b)	lepton(s)	B1
(c)	up down down changes to up up down **or** udd → uud **or** down changes to up **or** d → u	B1

277. 9702_w18_qp_22 Q: 8

	Answer	Mark
(a)	antineutrino **and** positron both underlined (and no other particles)	B1
(b)(i)	nucleon number = 27	A1
	proton number = 13	A1
(b)(ii)	weak (nuclear force/interaction)	B1
(b)(iii)	an (electron) antineutrino / $\bar{\nu}_{(e)}$ is produced (and this has energy)	B1
	X has kinetic energy	B1

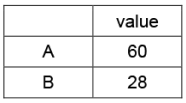
278. 9702_s17_qp_21 Q: 7

	Answer	Mark
(a)(i)	(proton is uud so) $(2/3)e + (2/3)e - (1/3)e = e$	B1
(a)(ii)	(neutron is udd so) $(2/3)e - (1/3)e - (1/3)e = 0$	B1
(b)(i)	 *all correct*	B1
(b)(ii)	weak (nuclear force/interaction)	B1
(b)(iii)	β^- decay: electron and (electron) antineutrino β^+ decay: positron and (electron) neutrino *all correct*	B1

279. 9702_s17_qp_22 Q: 8

	Answer	Mark
(a)	β^- emission: neutron changes to proton (+ beta$^-$/electron) **and** β^+ emission: proton changes to neutron (+ beta$^+$/positron)	B1
	β^- emission: (electron) antineutrino also emitted **and** β^+ emission: (electron) neutrino also emitted	B1
(b)	proton: up up down (and zero strange) neutron: up down down (and zero strange)	B1

280. 9702_s17_qp_23 Q: 7

	Answer	Mark
(a)	electron **and** quark both underlined/clearly indicated and no others	B1
(b)(i)	 *both correct*	B1
(b)(ii)	(electron) antineutrino	B1

281. 9702_w17_qp_21 Q: 8

	Answer	Mark
(a)	(quark structure is) up, down, down/udd	B1
	up/u has charge $+\frac{2}{3}(e)$, down/d has charge $-\frac{1}{3}(e)$	C1
	$+\frac{2}{3}e - \frac{1}{3}e - \frac{1}{3}e = 0$	A1
(b)	charge: p $+1.6(0) \times 10^{-19}$ (C) **or** $+e$ β^- $-1.6(0) \times 10^{-19}$ (C) **or** $-e$ $\bar{\nu}$ zero/0	B1
	mass: p 1.67×10^{-27} (kg)/1.7×10^{-27} (kg) β^- $9.1(1) \times 10^{-31}$ (kg) $\bar{\nu}$ very small/zero/0	B1

282. 9702_w17_qp_22 Q: 7

	Answer	Mark
(a)	lepton(s)	B1
(b)	protons: 7 **and** neutrons: 6	A1
(c)	$E = ½mv^2$	C1
	$= 0.80 \times 10^6 \times 1.60 \times 10^{-19}$	C1
	$= 1.28 \times 10^{-13}$ (J) $v^2 = 2 \times 1.28 \times 10^{-13} / 2.2 \times 10^{-26}$ $v = 3.4 \times 10^6\ \text{m s}^{-1}$	A1
(d)	an (electron) neutrino/$\nu_{(e)}$ is also produced (and this has energy)	B1

283. 9702_m16_qp_22 Q: 6

(a) $^{1}_{1}\text{p}$ B1

$^{0}_{-1}\beta^{-}$ and $^{0}_{0}\overline{\nu}$ B1

(b) an (electron) antineutrino B1

(c) lepton(s) B1

(d) **(i)** down, down, up / ddu B1

(ii) a down / d (quark) changes to an up / u (quark) **or** ddu → uud B1

284. 9702_s16_qp_21 Q: 7

(a) hadron: neutron/proton
and
lepton: electron/(electron) neutrino B1 [1]

(allow other correct particles)

(b) **(i)** proton: up up down or uud B1 [1]

(ii) neutron: up down down or udd B1 [1]

(c) **(i)** neutron → proton + electron + (electron) antineutrino B1 [1]

(ii) up down down (quarks) change to up up down (quarks)
or
down (quark) changes to up (quark) B1 [1]

285. 9702_s16_qp_22 Q: 8

(a) both electron and neutrino: lepton(s) B1

both neutron and proton: hadron(s)/baryon(s) B1 [2]

(b) **(i)** ${}^{1}_{1}\mathrm{p} \rightarrow {}^{1}_{0}\mathrm{n} + {}^{0}_{1}\beta + {}^{0}_{0}\nu$

correct symbols for particles M1

correct numerical values (allow no values on neutrino) A1 [2]

(ii) up up down or uud $\rightarrow$ up down down or udd B1 [1]

(iii) weak (nuclear) B1 [1]

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286. 9702_s16_qp_23 Q: 8

(a) α-particle is 2 protons and 2 neutrons; β^+-particle is positive electron/positron
α-particle has charge +2*e*; β^+-particle has +*e* charge
α-particle has mass 4u; β-particle has mass (1/2000)u
α-particle made up of hadrons; β^+-particle a lepton

any three B3 [3]

(b) ${}^{1}_{1}\mathrm{p} \rightarrow {}^{1}_{0}\mathrm{n} + {}^{0}_{1}\beta + {}^{0}_{0}\nu$

all terms correct M1

all numerical values correct (ignore missing values on ν) A1 [2]

(c) **(i)** **1.** proton: up, up, down / uud B1

2. neutron: up, down, down / udd B1 [2]

(ii) up quark has charge +2 / 3 (e) and down quark has charge –1 / 3 (e)
total is +1(e) B1 [1]

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287. 9702_w16_qp_21 Q: 7

(a) hadron not a fundamental particle/lepton is fundamental particle
or
hadron made of quarks/lepton not made of quarks
or
strong force/interaction acts on hadrons/does not act on leptons B1 [1]

(b) **(i)** proton: up, up, down / uud B1
neutron: up, down, down / udd B1 [2]

(ii) composition: 2(uud) + 2(udd)
= 6 up, 6 down / 6u, 6d B1 [1]

(c) **(i)** most of the atom is empty space
or
the nucleus (volume) is (very) small compared to the atom B1 [1]

(ii) nucleus is (positively) charged B1

the mass is concentrated in (very small) nucleus/small region/small volume/small core
or
the majority of mass in (very small) nucleus/small region/small volume/small core B1 [2]

288. 9702_w16_qp_22 Q: 6

(a) hadron not a fundamental particle/lepton is fundamental particle
or
hadron made of quarks/lepton not made of quarks
or
strong force/interaction acts on hadrons/does not act on leptons — B1 [1]

(b) (i) $^{0}_{1}e^{(+)}$ or $^{0}_{1}\beta^{(+)}$ — B1

$^{0}_{0}\nu_{(e)}$ — B1 [2]

(ii) weak (nuclear force / interaction) — B1 [1]

(iii)
- mass-energy
- momentum
- proton number
- nucleon number
- charge

Any three of the above quantities, 1 mark each — B3 [3]

(c) (quark structure of proton is) up, up, down or uud — B1

up/u (quark charge) is (+)⅔(*e*), down/d (quark charge) is –⅓(*e*) — C1

⅔*e* + ⅔*e* – ⅓*e* = (+)*e* — A1 [3]

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289. 9702_w16_qp_23 Q: 7

(a) hadron not a fundamental particle/lepton is fundamental particle
or
hadron made of quarks/lepton not made of quarks
or
strong force/interaction acts on hadrons/does not act on leptons — B1 [1]

(b) (i) proton: up, up, down / uud — B1
neutron: up, down, down / udd — B1 [2]

(ii) composition: 2(uud) + 2(udd)
= 6 up, 6 down / 6u, 6d — B1 [1]

(c) (i) most of the atom is empty space
or
the nucleus (volume) is (very) small compared to the atom — B1 [1]

(ii) nucleus is (positively) charged — B1

the mass is concentrated in (very small) nucleus/small region/small volume/small core
or
the majority of mass in (very small) nucleus/small region/small volume/small core — B1 [2]

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397. 9702_s20_MS_41 Q: 11

	Answer	Marks
(a)(i)	$E = mc^2$	C1
	$= 9.11 \times 10^{-31} \times (3.0 \times 10^8)^2$ $= 8.2 \times 10^{-14}$ J	A1
(a)(ii)	$p = h / \lambda$ **and** $E = hc / \lambda$ **or** $E = pc$	C1
	$p = (8.2 \times 10^{-14}) / (3.0 \times 10^8)$ $= 2.7 \times 10^{-22}$ N s	A1
(b)	total momentum (before and after interaction) is zero **or** momentum must be conserved (in the interaction) **or** momentum of the photons must be equal and opposite	B1
	(photons emitted in) opposite directions	B1

398. 9702_s20_MS_42 Q: 12

	Answer	Marks
(a)	difference between mass of nucleus and mass of (constituent) nucleons	M1
	where nucleons are separated to infinity	A1
(b)(i)	$E = mc^2$	C1
	$= 1.66 \times 10^{-27} \times (3.00 \times 10^8)^2 / (1.60 \times 10^{-13}) = 934$ MeV	A1
(b)(ii)	mass defect = $2 \times (1.007276 + 1.008665) - 4.001506$ $(= 0.030376)$	B1
	binding energy per nucleon = $(0.030376 \times 934) / 4 = 7.09$ MeV	A1
(c)	binding energy per nucleon is much greater	M1
	so would require a large amount of energy to separate the nucleons in helium	A1
	or	
	amount of energy released in forming hydrogen isotopes	(M1)
	is less than energy required to break apart helium nucleus	(A1)

399. 9702_s20_MS_43 Q: 11

	Answer	Marks
(a)(i)	$E = mc^2$	C1
	$= 9.11 \times 10^{-31} \times (3.0 \times 10^8)^2$ $= 8.2 \times 10^{-14}$ J	A1
(a)(ii)	$p = h / \lambda$ **and** $E = hc / \lambda$ **or** $E = pc$	C1
	$p = (8.2 \times 10^{-14}) / (3.0 \times 10^8)$ $= 2.7 \times 10^{-22}$ N s	A1
(b)	total momentum (before and after interaction) is zero **or** momentum must be conserved (in the interaction) **or** momentum of the photons must be equal and opposite	B1
	(photons emitted in) opposite directions	B1

400. 9702_m19_MS_42 Q: 12

	Answer	Marks
(a)(i)	fission	B1
(a)(ii)	*either* $^{0}_{-1}$e *or* $^{0}_{-1}\beta$	M1
	7	A1
(b)(i)	energy $= c^2 \Delta m$ $= 0.223 \times 1.66 \times 10^{-27} \times (3.00 \times 10^8)^2$	C1
	$= 3.33 \times 10^{-11}$ J	A1

	Answer	Marks
(b)(ii)	Any 2 from: kinetic energy of products gamma photons neutrinos	B2

401. 9702_w19_MS_41 Q: 12

	Answer	Marks
(a)	$E = (3.0 \times 10^8)^2 \times 1.66 \times 10^{-27}$ (= 1.49×10^{-10} J)	M1
	$= (1.49 \times 10^{-10}) / (1.60 \times 10^{-19}) = 9.34 \times 10^8 = 934$ MeV	A1
	or	
	binding energy = 8.443×95 [or equivalent using La-139 nucleus]	(M1)
	binding energy / mass defect = $(8.443 \times 95) / 0.859 = 934$ MeV	(A1)
(b)(i)	binding energy = 1.865×934 (= 1741.91 MeV)	C1
	binding energy per nucleon = 1741.91 / 235 = 7.41 (MeV)	A1
(b)(ii)	less (than)	B1
(c)	energy = $\{(1.219 + 0.859) - 1.865)\} \times 934$ **or** energy = $(95 \times 8.443) + (139 \times 8.189) - (235 \times 7.412)$	C1
	= 199 MeV	A1
(d)	number of reactions = $1.2 \times 10^{-7} \times 6.02 \times 10^{23}$ = 7.22×10^{16}	C1
	energy release (for one reaction) = $199 \times 1.60 \times 10^{-13}$ (= 3.18×10^{-11} J)	C1
	power = $(7.22 \times 10^{16} \times 3.18 \times 10^{-11}) / (25 \times 10^{-3})$ = 9.2×10^7 W	A1

402. 9702_w19_MS_43 Q: 12

	Answer	Marks
(a)	$E = (3.0 \times 10^8)^2 \times 1.66 \times 10^{-27}$ (= 1.49×10^{-10} J)	M1
	$= (1.49 \times 10^{-10}) / (1.60 \times 10^{-19}) = 9.34 \times 10^8 = 934$ MeV	A1
	or	
	binding energy = 8.443×95 [or equivalent using La-139 nucleus]	(M1)
	binding energy / mass defect = $(8.443 \times 95) / 0.859 = 934$ MeV	(A1)
(b)(i)	binding energy = 1.865×934 (= 1741.91 MeV)	C1
	binding energy per nucleon = 1741.91 / 235 = 7.41 (MeV)	A1
(b)(ii)	less (than)	B1
(c)	energy = $\{(1.219 + 0.859) - 1.865)\} \times 934$ **or** energy = $(95 \times 8.443) + (139 \times 8.189) - (235 \times 7.412)$	C1
	= 199 MeV	A1
(d)	number of reactions = $1.2 \times 10^{-7} \times 6.02 \times 10^{23}$ = 7.22×10^{16}	C1
	energy release (for one reaction) = $199 \times 1.60 \times 10^{-13}$ (= 3.18×10^{-11} J)	C1
	power = $(7.22 \times 10^{16} \times 3.18 \times 10^{-11}) / (25 \times 10^{-3})$ = 9.2×10^7 W	A1

403. 9702_m18_MS_42 Q: 3

	Answer	Marks
(a)	reasonably shaped circle or oval surrounding the origin	B1
	closed loop passing through $(0, \pm v_0)$ and $(\pm x_0, 0)$	B1
(b)	line from (0,0) to (90, F_0)	B1
	curve with decreasing positive gradient, zero gradient at $\theta = 90$	B1
(c)	reasonable sinusoidal wave, one cycle, period 4.0 ms	B1
	amplitude at 4.0 V	B1
(d)	U near right-hand end of line with Ba between U and peak of graph	B1
	Ba on right hand side of peak and Kr between Ba and peak of graph	B1

404. 9702_w18_MS_41 Q: 11

	Answer	Marks
(a)	discrete amount/quantum/packet of energy	M1
	of electromagnetic radiation	A1
(b)(i)	energy = hc/λ	C1
	$\lambda = (6.63 \times 10^{-34} \times 3.00 \times 10^{8})/(0.51 \times 10^{6} \times 1.60 \times 10^{-19})$ $= 2.4 \times 10^{-12}$ m	A1
(b)(ii)	$p = h/\lambda$ $= (6.63 \times 10^{-34})/(2.44 \times 10^{-12})$ **or** $p = E/c$ $= (0.51 \times 1.60 \times 10^{-13})/(3.00 \times 10^{8})$	C1
	$p = 2.7 \times 10^{-22}$ Ns	A1
(c)(i)	$E = c^2\Delta m$	C1
	$\Delta m = (0.51 \times 1.60 \times 10^{-13})/(3.00 \times 10^{8})^2$ $= 9.1 \times 10^{-31}$ kg	A1
(c)(ii)	(momentum is conserved so) nucleus must have momentum in opposite direction to photon	B1

405. 9702_w18_MS_42 Q: 12

	Answer	Marks
(a)	fusion: two nuclei combine to form a (single) nucleus	B1
	fission: a (single) large nucleus divides to form (smaller) nuclei	B1
	Any one from: • fusion is initiated by (very) high temperatures • fission is initiated by neutron bombardment • resulting nuclei in fission are of similar size • (both processes) release energy • binding energy per nucleon increases • total binding energy increases • fission involves release of neutrons	B1
12(b)(i)	neutron	B1
12(b)(ii)	**1.** zero	A1
	2. $(4 \times 11.3290 \times 10^{-13}) - (2 \times 1.7813 \times 10^{-13}) - (3 \times 4.5285 \times 10^{-13})$	C1
	energy change $= 45.316 \times 10^{-13} - 17.148 \times 10^{-13}$ $= 2.82 \times 10^{-12}$ J	A1
(b)(iii)	1.0 mol or N_A nuclei of each energy $= 2.817 \times 10^{-12} \times 6.02 \times 10^{23}$ $= 1.7 \times 10^{12}$ J	A1

406. 9702_w18_MS_43 Q: 11

	Answer	Marks
(a)	discrete amount/quantum/packet of energy	M1
	of electromagnetic radiation	A1
(b)(i)	energy = hc/λ	C1
	$\lambda = (6.63 \times 10^{-34} \times 3.00 \times 10^{8})/(0.51 \times 10^{6} \times 1.60 \times 10^{-19})$ $= 2.4 \times 10^{-12}$ m	A1
(b)(ii)	$p = h/\lambda$ $= (6.63 \times 10^{-34})/(2.44 \times 10^{-12})$ **or** $p = E/c$ $= (0.51 \times 1.60 \times 10^{-13})/(3.00 \times 10^{8})$	C1
	$p = 2.7 \times 10^{-22}$ Ns	A1
(c)(i)	$E = c^2\Delta m$	C1
	$\Delta m = (0.51 \times 1.60 \times 10^{-13})/(3.00 \times 10^{8})^2$ $= 9.1 \times 10^{-31}$ kg	A1
(c)(ii)	(momentum is conserved so) nucleus must have momentum in opposite direction to photon	B1

407. 9702_m17_MS_42 Q: 12

	Answer	Marks
(a)	*either*	
	(minimum) energy required/work done to separate the nucleons (in a nucleus)	M1
	to infinity	A1
	or	
	energy released when nucleons come together (to form a nucleus)	(M1)
	from infinity	(A1)
(b)(i)	(total) binding energy of thorium and helium (nuclei) greater than binding energy of uranium (nucleus)	B1
(b)(ii)1	change in mass = 238.05076 – (234.04357 + 4.00260) $= 4.59 \times 10^{-3}$ u	A1
(b)(ii)2	*either*	
	$E = mc^2$ $= 4.59 \times 10^{-3} \times 1.66 \times 10^{-27} \times (3.00 \times 10^{8})^2$	C1
	$= 6.9 \times 10^{-13}$ J	A1
	or	
	1u = 931 MeV $E = 4.59 \times 10^{-3} \times 931 \times 10^{6} \times 1.6 \times 10^{-19}$	(C1)
	$= 6.8 \times 10^{-13}$ J	(A1)
(b)(iii)	Th nucleus/He nucleus/product nucleus has kinetic energy	M1
	energy of gamma photon must be less than energy released	A1

408. 9702_s17_MS_41 Q: 12

	Answer	Marks
(a)	$x = 7$	A1
(b)(i)	$E = mc^2$	C1
	$= 1.66 \times 10^{-27} \times (3.0 \times 10^8)^2$ $= 1.494 \times 10^{-10}$ J	C1
	division by 1.6×10^{-13} clear to give 934 MeV	A1
(b)(ii)	$\Delta m = (235.123 + 1.00863) - (94.945 + 138.955 + 2 \times 1.00863 + 7 \times 5.49 \times 10^{-4})$ **or** $\Delta m = 235.123 - (94.945 + 138.955 + 1 \times 1.00863 + 7 \times 5.49 \times 10^{-4})$	C1
	$= 0.21053$ u	C1
	energy $= 0.21053 \times 934$ $= 197$ MeV	A1
(c)	kinetic energy of nuclei/particles/products/fragments	B1
	γ–ray photon energy	B1

409. 9702_s17_MS_42 Q: 12

	Answer	Marks
(a)	$7\ {}^{0}_{-1}e$	A1
(b)(i)	$E = mc^2$	C1
	$= 1.66 \times 10^{-27} \times (3.00 \times 10^8)^2$	M1
	$= 1.494 \times 10^{-10}$ J division by 1.60×10^{-13} clear to give 934 MeV	A1
(b)(ii)	$\Delta m = (82 \times 1.00863\text{u}) + (57 \times 1.00728\text{u}) - 138.955\text{u}$ $= (-)\ 1.16762$ (u)	C1
	energy $= 1.16762 \times 934$	C1
	energy per nucleon $= (1.16762 \times 934) / 139$ $= 7.85$ MeV	A1
(c)	above $A = 56$, binding energy per nucleon decreases as A increases	B1
	U-235 has larger nucleon number	M1
	so less (binding energy per nucleon)	A1
	or	
	fission takes place with uranium	(B1)
	fission reaction releases energy	(M1)
	binding energy per nucleon less (for uranium than for products)	(A1)

410. 9702_s17_MS_43 Q: 12

	Answer	Marks
(a)	$x = 7$	A1
(b)(i)	$E = mc^2$	C1
	$= 1.66 \times 10^{-27} \times (3.0 \times 10^8)^2$ $= 1.494 \times 10^{-10}$ J	C1
	division by 1.6×10^{-13} clear to give 934 MeV	A1
(b)(ii)	$\Delta m = (235.123 + 1.00863) - (94.945 + 138.955 + 2 \times 1.00863 + 7 \times 5.49 \times 10^{-4})$ **or** $\Delta m = 235.123 - (94.945 + 138.955 + 1 \times 1.00863 + 7 \times 5.49 \times 10^{-4})$	C1
	$= 0.21053$ u	C1
	energy $= 0.21053 \times 934$ $= 197$ MeV	A1
(c)	kinetic energy of nuclei/particles/products/fragments	B1
	γ–ray photon energy	B1

411. 9702_m16_MS_42 Q: 9

(a) direction of force due to electric field opposite to force due to magnetic field B1
electric field is up the page B1 [2]

(b) force due to electric field = force due to magnetic field or $Eq = Bqv$ B1
$E = Bv$ C1
$= 9.7 \times 10^{-2} \times 1.6 \times 10^5$
$= 1.6\ (1.55) \times 10^4\ \text{V m}^{-1}$ A1 [3]

(c) $q/m = v/Br$ C1
$= 1.6 \times 10^5 / (9.7 \times 10^{-2} \times 4.0 \times 10^{-2})$ C1
$= 4.1\ (4.12) \times 10^7\ \text{C kg}^{-1}$ A1 [3]

(d) **(i)** $m = (3 \times 1.60 \times 10^{-19}) / (4.12 \times 10^7)$ C1
$m = 1.16 \times 10^{-26} / 1.66 \times 10^{-27}$
$= 7(.0)$ u (*allow* 7.1 u) A1 [2]

(ii) 3 protons, 4 neutrons A1 [1]

412. 9702_w16_MS_42 Q: 14

(a) (i) ^4_2He or $^4_2\alpha$ B1 [1]

(ii) ^1_0n B1 [1]

(b) (i) Δm = (29.97830 +1.00867) – (26.98153 + 4.00260) C1

= 30.98697 – 30.98413

= 2.84×10^{-3} u C1 [2]

(ii) $E = c^2\Delta m$ or mc^2 C1

= $(3.0 \times 10^8)^2 \times 2.84 \times 10^{-3} \times 1.66 \times 10^{-27}$

= 4.2×10^{-13} J A1 [2]

(c) mass of products is greater than mass of Al plus α
or
reaction causes (net) increase in (rest) mass (of the system) B1

α-particle must have at least this amount of kinetic energy B1 [2]

413. 9702_m21_MS_42 Q: 12

	Answer	Marks
(a)	1 not affected by external factors	**B1**
	2 cannot predict when a (particular) nucleus will decay *or* cannot predict which nucleus will decay (next)	**B1**
(b)(i)	Number of atoms = $\frac{1.0\times10^{-9}}{90\times1.66\times10^{-27}}$ *or* $\frac{1.0\times10^{-9}\times6.02\times10^{23}}{90\times10^{-3}}$ $= 6.693\times10^{15}$	**C1**
	$A = \lambda N$ $\lambda = \frac{5.2\times10^{6}}{6.693\times10^{15}}$	**C1**
	$\lambda = 7.8\times10^{-10}$ s^{-1}	**A1**
(b)(ii)	daughter nucleus is unstable	**B1**

414. 9702_s21_MS_41 Q: 6

	Answer	Marks
(a)	from $x = 0$ to $x = r$: $E = 0$	B1
	from $x = r$ to $x = 3r$: curve with negative gradient of decreasing magnitude passing through (r, E_0)	B1
	line passing through $(2r, E_0 / 4)$ and $(3r, E_0 / 9)$	B1
(b)	from $p = p_0 / 2$ to $p = p_0$: curve with negative gradient of decreasing magnitude passing through (p_0, λ_0)	B1
	line passing through $(½p_0, 2\lambda_0)$	B1
(c)	from $t = 0$ to $t = 45$ s: curve with positive gradient of decreasing magnitude starting at (0, 0)	B1
	line passing through $(15, ½N_0)$	B1
	line passing through $(30, 0.75N_0)$ and $(45, 0.88N_0)$	B1

415. 9702_s21_MS_42 Q: 5

	Answer	Marks
(a)	from $x = 0$ to $x = r$: horizontal line at $V = 1.0V_0$	B1
	from $x = r$ to $x = 3r$: curve with negative gradient of decreasing magnitude starting at $(r, 1.0V_0)$	B1
	line passing through $(2r, ½V_0)$ and $(3r, ⅓V_0)$	B1
(b)	line with negative gradient from $\lambda = ⅓\lambda_0$ to $\lambda = \lambda_0$	B1
	line passing through $(\lambda_0, 0)$	B1
	curve with negative gradient of decreasing magnitude passing through $(½\lambda_0, E_{MAX})$ and $(⅓\lambda_0, 2E_{MAX})$	B1
(c)	$1.0T_{½}$ shown at $½N_0$ **and** $2.0T_{½}$ shown at $¼N_0$	B1
	line starting at (0, 0) and reaching $(T, N_0–N)$	B1
	line starting at (0, 0) and reaching original curve at $(1.0T_{½}, ½N_0)$	B1

416. 9702_s21_MS_43 Q: 6

	Answer	Marks
(a)	from $x = 0$ to $x = r$: $E = 0$	B1
	from $x = r$ to $x = 3r$: curve with negative gradient of decreasing magnitude passing through (r, E_0)	B1
	line passing through $(2r, E_0 / 4)$ and $(3r, E_0 / 9)$	B1
(b)	from $p = p_0 / 2$ to $p = p_0$: curve with negative gradient of decreasing magnitude passing through (p_0, λ_0)	B1
	line passing through $(½p_0, 2\lambda_0)$	B1
(c)	from $t = 0$ to $t = 45$ s: curve with positive gradient of decreasing magnitude starting at (0, 0)	B1
	line passing through $(15, ½N_0)$	B1
	line passing through $(30, 0.75N_0)$ and $(45, 0.88N_0)$	B1

417. 9702_w21_MS_41 Q: 12

	Answer	Marks
(a)	probability of decay (of a nucleus)	M1
	per unit time	A1
(b)	$A = \lambda N$	C1
	N = mass / (nucleon number × u)	C1
	$2.92 \times 10^9 = (\lambda \times 5.87 \times 10^{-10}) / (131 \times 1.66 \times 10^{-27})$ $\lambda = 1.08 \times 10^{-6}\ s^{-1}$	A1
(c)	• sample emits radiation in all directions • some radiation is absorbed by air/detector window • self-absorption within the source • dead time/inefficiency of detector *Any two points, 1 mark each*	B2

418. 9702_w21_MS_42 Q: 12

	Answer	Marks
(a)(i)	cannot predict when a particular nucleus will decay **or** cannot predict which nucleus will decay next	B1
(a)(ii)	(decay is) not affected by external (environmental) factors	B1
(b)(i)	$A = A_0 \exp(-\lambda t)$ and so $\ln A = \ln A_0 - \lambda t$ gradient of line = $(-)\lambda$	C1
	λ = (36.4 – 35.0) / (20 – 0) (= 0.07(0) min^{-1})	C1
	half-life = ln 2 / λ = ln 2 / 0.070 = 10 min	A1
	or	
	$A_0 = \exp(-36.4) = 6.43 \times 10^{15}$ (Bq)	(C1)
	$A_0 / 2 = 3.21 \times 10^{15}$ (Bq), so ln (A_0 / 2) = 35.7	(C1)
	read off half-life = 10 min	(A1)
	or	
	(at one half-life,) ln A = 36.4 – ln 2	(C1)
	= 35.7	(C1)
	read off half-life = 10 min	(A1)

	Answer	Marks
(b)(ii)	$A = \lambda N$	C1
	N = mass / (nucleon number × u) **or** N = (mass / nucleon number) × N_A	C1
	$\exp(36.4) = (1.17 \times 10^{-3} \times 5.66 \times 10^{-7}) / (\text{nucleon number} \times 1.66 \times 10^{-27})$ **or** $\exp(36.4) = (1.17 \times 10^{-3} \times 5.66 \times 10^{-4} \times 6.02 \times 10^{23}) / \text{nucleon number}$ nucleon number = 62	A1

419. 9702_w21_MS_43 Q: 12

	Answer	Marks
(a)	probability of decay (of a nucleus)	M1
	per unit time	A1
(b)	$A = \lambda N$	C1
	N = mass / (nucleon number × u)	C1
	$2.92 \times 10^9 = (\lambda \times 5.87 \times 10^{-10}) / (131 \times 1.66 \times 10^{-27})$ $\lambda = 1.08 \times 10^{-6}\ s^{-1}$	A1
(c)	• sample emits radiation in all directions • some radiation is absorbed by air/detector window • self-absorption within the source • dead time/inefficiency of detector *Any two points, 1 mark each*	B2

420. 9702_m20_MS_42 Q: 12

	Answer	Marks
(a)	(minimum) energy required to separate the nucleons	M1
	to infinity	A1
(b)(i)	**37** **2**	B1
(b)(ii)	fission	B1
(b)(iii)	binding energy per nucleon smaller for U than for Cs	B1
(c)	Current ratio 2 Y to 1 Zr, so initially 3 Y $2 = 3\,e^{-\lambda t}$ $\lambda = 0.693 / 2.7$	C1
	$\ln(2/3) = -(\ln 2 / 2.7)t$	C1
	t = **1.6** days	A1
	or	
	$(½)^n = 2/3$	(C1)
	n = 0.585	(C1)
	time = 0.585 × 2.7 = **1.6** days	(A1)

421. 9702_s20_MS_41 Q: 12

	Answer	Marks
(a)(i)	time at which a nucleus will decay cannot be predicted **or** constant probability of decay of a nucleus	**B1**
(a)(ii)	decay (of a nucleus) not affected by environmental factors	**B1**
(b)	$A = A_0e^{-\lambda t}$ **and** $\lambda = \ln 2 / t_{½}$	**C1**
	$= 3.6 \times 10^5 \times \exp [-(2 \times \ln 2) / 1.4]$	**C1**
	or	
	$A = A_0 \times 0.5^N$	**(C1)**
	$= 3.6 \times 10^5 \times 0.5^N$ where $N = 2 / 1.4$	**(C1)**
	$A = 1.3 \times 10^5$ Bq	**A1**
(c)(i)	smooth curve, starting at $(0, 3.6 \times 10^5)$ and passing through $(1.4, 1.8 \times 10^5)$ and $(2.0, 1.3 \times 10^5)$	**B1**
(c)(ii)	(activity of sample is greater than activity of X so) there must be an additional source of activity	**C1**
	the decay product (of isotope X) is radioactive	**A1**

422. 9702_s20_MS_43 Q: 12

	Answer	Marks
(a)(i)	time at which a nucleus will decay cannot be predicted **or** constant probability of decay of a nucleus	**B1**
(a)(ii)	decay (of a nucleus) not affected by environmental factors	**B1**
(b)	$A = A_0e^{-\lambda t}$ **and** $\lambda = \ln 2 / t_{½}$	**C1**
	$= 3.6 \times 10^5 \times \exp [-(2 \times \ln 2) / 1.4]$	**C1**
	or	
	$A = A_0 \times 0.5^N$	**(C1)**
	$= 3.6 \times 10^5 \times 0.5^N$ where $N = 2 / 1.4$	**(C1)**
	$A = 1.3 \times 10^5$ Bq	**A1**
12(c)(i)	smooth curve, starting at $(0, 3.6 \times 10^5)$ and passing through $(1.4, 1.8 \times 10^5)$ and $(2.0, 1.3 \times 10^5)$	**B1**
(c)(ii)	(activity of sample is greater than activity of X so) there must be an additional source of activity	**C1**
	the decay product (of isotope X) is radioactive	**A1**

423. 9702_s19_MS_41 Q: 12

	Answer	Marks
(a)(i)	$\Delta N / \Delta T$	**B1**
(a)(ii)	$\Delta N / N$	**B1**
(a)(iii)	$\Delta N / (N \Delta T)$	**B1**
(b)(i)	**1.** mass change $= 5.60 \times 10^{-3}$ u	**A1**
	2. energy $= (\Delta)mc^2$	**C1**
	$= 5.6 \times 10^{-3} \times 1.66 \times 10^{-27} \times (3.0 \times 10^8)^2$ $(= 8.36 \times 10^{-13}$ J)	**C1**
	$= 0.84$ pJ	**A1**
(b)(ii)	kinetic energy (of recoil) of lead (nucleus)	**B1**
	energy of γ-ray photon	**B1**

424. 9702_s19_MS_42 Q: 12

	Answer	Marks
(a)	energy required to separate the nucleons (in a nucleus)	M1
	to infinity	A1
	or	
	energy released when nucleons come together (to form nucleus)	(M1)
	from infinity	(A1)
(b)	mass defect = 140.911 – (57 × 1.007) – (84 × 1.009)	C1
	= 140.911 – 142.155 = (–)1.244 (u)	C1
	energy = $c^2(\Delta)m$	C1
	= $(3.00 \times 10^8)^2 \times 1.244 \times 1.66 \times 10^{-27}$ = 1.9×10^{-10} J	A1
(c)(i)	$A = A_0e^{-\lambda t}$ **and** $\ln 2 = \lambda t_{½}$	C1
	$0.40 = \exp(-\ln 2 \times t / 3.9)$	C1
	or	
	$(0.5)^n = 0.40$	(C1)
	$n = 1.32$ **and** $t = 1.32 \times 3.9$	(C1)
	$t = 5.2$ hours	A1
(c)(ii)	daughter product may be radioactive **or** random nature of decay	B1

425. 9702_s19_MS_43 Q: 12

	Answer	Marks
(a)(i)	$\Delta N / \Delta T$	B1
(a)(ii)	$\Delta N / N$	B1
(a)(iii)	$\Delta N / (N \Delta T)$	B1
(b)(i)	**1.** mass change = 5.60×10^{-3} u	A1
	2. energy = $(\Delta)mc^2$	C1
	= $5.6 \times 10^{-3} \times 1.66 \times 10^{-27} \times (3.0 \times 10^8)^2$ (= 8.36×10^{-13} J)	C1
	= 0.84 pJ	A1
(b)(ii)	kinetic energy (of recoil) of lead (nucleus)	B1
	energy of γ-ray photon	B1

426. 9702_w19_MS_42 Q: 12

	Answer	Marks
(a)(i)	(decay is) unpredictable/cannot be predicted	B1
(a)(ii)	probability of decay (of a nucleus)	M1
	per unit time	A1
(b)	$A = \lambda N$	C1
	(for 1.00 m^3) $A = 0.600 / 4.80 \times 10^{-3}$ (= 125 Bq)	C1
	$N = 125 / ([7.55 \times 10^{-3}] / 3600)$ $(= 5.96 \times 10^7)$	C1
	so ratio = $(2.52 \times 10^{25}) / (5.96 \times 10^7)$	C1
	or	
	(for 4.80×10^{-3} m^3) N for air = $2.52 \times 10^{25} \times 4.80 \times 10^{-3}$ $(= 1.21 \times 10^{23})$	(C1)
	N for radon = $0.600 / ([7.55 \times 10^{-3}] / 3600)$ $(= 2.86 \times 10^5)$	(C1)
	so ratio = $(1.21 \times 10^{23}) / (2.86 \times 10^5)$	(C1)
	ratio = 4.2×10^{17}	A1

427. 9702_m18_MS_42 Q: 13

	Answer	Marks
(a)(i)	probability of decay (of a nucleus)	M1
	per unit time	A1
(a)(ii)	$A = A_0 e^{-\lambda t}$ after one half-life, $½A_0 = A_0 e^{-\lambda t_{1/2}}$	M1
	$½ = \exp(-\lambda t_{½})$ and hence taking logs, $\ln 2 = \lambda t_{½}$	A1
(b)	activity = $3.8 \times 10^4 \exp(-\ln 2 \times 36 / 15)$	C1
	= 7200 Bq	C1
	or activity = $3.8 \times 10^4 / 2^{2.4}$	(C1)
	= 7200 Bq	(C1)
	volume = $(7200 / 1.2) \times 5.0$	C1
	= 3.0×10^4 cm^3	A1
	OR activity of 5.0 cm^3 = $1.2 \times 2^{2.4}$	(C1)
	= 6.3336 Bq	(C1)
	volume = $(3.8 \times 10^4 / 6.3336) \times 5.0$	(C1)
	= 3.0×10^4 cm^3	(A1)

428. 9702_s18_MS_41 Q: 13

	Answer	Marks
(a)	emission of particles/radiation by unstable nucleus	B1
	spontaneous emission	B1
(b)(i)	use of graph to determine half-life = 14 minutes	B1
	hence $\lambda = \ln 2 / (14 \times 60)$ (s^{-1})	C1
	N at 14 minutes = 4.4×10^7 **and** $A = \lambda N$	C1
	activity $= 4.4 \times 10^7 \times \ln 2 / (14 \times 60)$ $= 3.6 \times 10^4$ Bq	A1
	or	
	correct tangent drawn at time t = 14 minutes	(B1)
	magnitude of gradient of tangent identified as activity	(C1)
	correct working for gradient leading to activity	(C1)
	activity = 3.6×10^4 Bq	(A1)
(b)(ii)	$3.6 \times 10^4 = \lambda \times 4.4 \times 10^7$ **or** $\lambda = \ln 2 / (14.0 \times 60)$	C1
	$\lambda = 8.2 \times 10^{-4}$ s^{-1}	A1

429. 9702_s18_MS_42 Q: 12

	Answer	Marks
(a)	emission of particles/radiation by unstable nucleus	B1
	spontaneous emission	B1
(b)(i)	P – the curve that starts with a high number D – the curve with the peak S – the curve that increases from zero throughout *(one correct 1 mark, all three correct 2 marks)*	B2
(b)(ii)	$\lambda t_{½} = 0.693$ $\lambda = 0.693 / (60.0 \times 60)$	C1
	$= 1.93 \times 10^{-4}$ s^{-1}	A1
(c)	half-life of F is much shorter than half-life of E	B1
	nuclei of F decay (almost) as soon as they are produced	B1

430. 9702_s18_MS_43 Q: 13

	Answer	Marks
(a)	emission of particles/radiation by unstable nucleus	B1
	spontaneous emission	B1
(b)(i)	use of graph to determine half-life = 14 minutes	B1
	hence $\lambda = \ln 2 / (14 \times 60)$ (s^{-1})	C1
	N at 14 minutes = 4.4×10^7 **and** $A = \lambda N$	C1
	activity $= 4.4 \times 10^7 \times \ln 2 / (14 \times 60)$ $= 3.6 \times 10^4$ Bq	A1
	or	
	correct tangent drawn at time t = 14 minutes	(B1)
	magnitude of gradient of tangent identified as activity	(C1)
	correct working for gradient leading to activity	(C1)
	activity = 3.6×10^4 Bq	(A1)
(b)(ii)	$3.6 \times 10^4 = \lambda \times 4.4 \times 10^7$ **or** $\lambda = \ln 2 / (14.0 \times 60)$	C1
	$\lambda = 8.2 \times 10^{-4}$ s^{-1}	A1

431. 9702_w18_MS_41 Q: 12

	Answer	Marks
(a)	unstable nucleus	B1
	emission of particles/photons	B1
	emission is spontaneous **or** (particles/radiation) are ionising	B1
(b)(i)	tangent drawn and gradient calculation attempted	B1
	activity = 1.3×10^6 Bq (*1 mark for answer within* $\pm 0.2 \times 10^6$ Bq, *2 marks for answer within* $\pm 0.1 \times 10^6$ Bq)	A2
(b)(ii)	$A = \lambda N$	C1
	$\lambda = (1.3 \times 10^6) / (3.05 \times 10^{10}) = 4.3 \times 10^{-5}$ s^{-1} ($\approx 4 \times 10^{-5}$ s^{-1})	A1
(c)	$A = A_0 e^{-\lambda t}$ $1.0 \times 10^3 = 4.6 \times 10^3 \exp(-5.5 \times 10^{-7} \times t)$	C1
	$\ln (4.6) = 5.5 \times 10^{-7} \times t$	C1
	$t = 2.78 \times 10^6$ s = 32 days	A1

432. 9702_w18_MS_43 Q: 12

	Answer	Marks
(a)	unstable nucleus	B1
	emission of particles/photons	B1
	emission is spontaneous **or** (particles/radiation) are ionising	B1
(b)(i)	tangent drawn and gradient calculation attempted	B1
	activity = 1.3×10^6 Bq (*1 mark for answer within* $\pm 0.2 \times 10^6$ Bq, *2 marks for answer within* $\pm 0.1 \times 10^6$ Bq)	A2
(b)(ii)	$A = \lambda N$	C1
	$\lambda = (1.3 \times 10^6)/(3.05 \times 10^{10}) = 4.3 \times 10^{-5}\,s^{-1}$ ($\approx 4 \times 10^{-5}\,s^{-1}$)	A1
(c)	$A = A_0 e^{-\lambda t}$ $1.0 \times 10^3 = 4.6 \times 10^3 \exp(-5.5 \times 10^{-7} \times t)$	C1
	$\ln(4.6) = 5.5 \times 10^{-7} \times t$	C1
	$t = 2.78 \times 10^6$ s = 32 days	A1

433. 9702_w17_MS_41 Q: 12

	Answer	Marks
(a)	• emission from radioactive daughter products • self-absorption in source • absorption in air before reaching detector • detector not sensitive to all radiations • window of detector may absorb some radiation • dead-time of counter • background radiation *Any two points.*	B2
(b)(i)	curve is not smooth **or** curve fluctuates/curve is jagged	B1
(b)(ii)	clear evidence of allowance for background	B1
	half-life determined at least twice	B1
	half-life = 1.5 hours (*1 mark if in range 1.7–2.0; 2 marks if in range 1.4–1.6*)	A2
(c)	**1.** half-life: no change	M1
	because decay is spontaneous/independent of environment	A1
	2. count rate (likely to be or could be) different/is random/cannot be predicted	B1

434. 9702_w17_MS_42 Q: 12

	Answer	Marks
(a)(i)	nucleus emits particles/EM radiation/ionising radiation	B1
	emission/release from unstable nucleus **or** emission from nucleus is random and/or spontaneous	B1
(a)(ii)	probability of decay (of a nucleus) **or** fraction of (number of undecayed) nuclei that will decay	M1
	per unit time	A1
(b)	energy is shared with another particle	B1
	mention of antineutrino	B1
(c)(i)	number $= [(1.2 \times 10^{-9}) / 131] \times 6.02 \times 10^{23}$ **or** number $= (1.2 \times 10^{-3} \times 10^{-9}) / (131 \times 1.66 \times 10^{-27})$ $(= 5.51 \times 10^{12})$	C1
	$A = \lambda N$	C1
	$= [0.086 / (24 \times 3600)] \times 5.51 \times 10^{12}$ $= 5.5 \times 10^{6}$ Bq	A1
(c)(ii)	$1 / 50 = \exp(-0.086t)$ **or** $1 / 50 = 0.5^{n}$	C1
	$t = 45$ days	A1

435. 9702_w17_MS_43 Q: 12

	Answer	Marks
(a)	• emission from radioactive daughter products • self-absorption in source • absorption in air before reaching detector • detector not sensitive to all radiations • window of detector may absorb some radiation • dead-time of counter • background radiation *Any two points.*	B2
(b)(i)	curve is not smooth **or** curve fluctuates/curve is jagged	B1
(b)(ii)	clear evidence of allowance for background	B1
	half-life determined at least twice	B1
	half-life = 1.5 hours (*1 mark if in range 1.7–2.0; 2 marks if in range 1.4–1.6*)	A2
(c)	**1.** half-life: no change	M1
	because decay is spontaneous/independent of environment	A1
	2. count rate (likely to be or could be) different/is random/cannot be predicted	B1

436. 9702_m16_MS_42 Q: 13

(a) $\lambda = \ln 2 / T_{½}$
$= \ln 2 / (53.3 \times 24 \times 60 \times 60) = 1.5 \times 10^{-7}\ s^{-1}$ A1 [1]

(b) $A = \lambda N$ C1
$N = 39 \times 10^{-3} / 1.5 \times 10^{-7} = 2.6 \times 10^{5}$
$m = (2.6 \times 10^{5} / 6.0 \times 10^{23}) \times 7 \times 10^{-3}$ *or* $2.6 \times 10^{5} \times 1.66 \times 10^{-27} \times 7$ C1
$= 3.0 \times 10^{-21}$ kg A1 [3]

(c) $2/39 = \exp(-1.5 \times 10^{-7} \times t)$ *or* $2/39 = (1/2)^{[t/(53.3 \times 24 \times 3600)]}$ C1
$t = 2.0 \times 10^{7}$ s A1 [2]

437. 9702_w16_MS_41 Q: 12

(a) **(i)** time for number of atoms/nuclei or activity to be reduced to one half M1

reference to (number of…) original nuclide/single isotope
or
reference to half of original value/initial activity A1 [2]

(ii) $A = A_0 \exp(-\lambda t)$ and either $t = t_{½}$, $A = ½A_0$ or $½A_0 = A_0 \exp(-\lambda t_{½})$ M1

so $\ln 2 = \lambda t_{½}$ (and $\ln 2 = 0.693$), hence $0.693 = \lambda t_{½}$ A1 [2]

(b) $A = \lambda N$

$N = 200 / (2.1 \times 10^{-6})$ C1

$= 9.52 \times 10^{7}$ C1

mass $= (9.52 \times 10^{7} \times 222 \times 10^{-3}) / (6.02 \times 10^{23})$
or
mass $= 9.52 \times 10^{7} \times 222 \times 1.66 \times 10^{-27}$ C1

$= 3.5 \times 10^{-17}$ kg A1 [4]

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438. 9702_w16_MS_43 Q: 12

(a) (i) time for number of atoms/nuclei or activity to be reduced to one half — M1

reference to (number of…) original nuclide/single isotope
or
reference to half of original value/initial activity — A1 [2]

(ii) $A = A_0 \exp(-\lambda t)$ and either $t = t_{½}$, $A = ½A_0$ or $½A_0 = A_0 \exp(-\lambda t_{½})$ — M1

so $\ln 2 = \lambda t_{½}$ (and $\ln 2 = 0.693$), hence $0.693 = \lambda t_{½}$ — A1 [2]

(b) $A = \lambda N$

$N = 200 / (2.1 \times 10^{-6})$ — C1

$= 9.52 \times 10^{7}$ — C1

mass $= (9.52 \times 10^{7} \times 222 \times 10^{-3}) / (6.02 \times 10^{23})$
or
mass $= 9.52 \times 10^{7} \times 222 \times 1.66 \times 10^{-27}$ — C1

$= 3.5 \times 10^{-17}$ kg — A1 [4]

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Q1.

6	(a)	(i)	curve is not smooth, fluctuations, etc B1		
		(ii)	curve is same shape or same half-life, not affected by temperature, etc..... ..... B1		[2]
	(b)	(i)	134..... ..... B1		[1]
		(ii)	α-particle shown as $^4_2\mathrm{He}$ or as $^4_2\alpha$ ..... B1 nucleon number of Po shown as 216 ..... B1 proton number of Po shown as 84..... B1		[3]

Q2.

8	(a)	position shown as $A = 227$, $Z = 91$	B1	**[1]**
	(b)	Pu shown as $A = 243$, $Z = 94$ D shown with $A = A_{Pu}$ and with $Z = (Z_{Pu} + 1)$	B1 B1	**[2]**

Q3.

8	(a)	nucleus emits α- or β- particles and/or γ-rays	M1 A1	**[2]**
	(b)	decay unaffected by environmental changes such as temperature, pressure etc. *(one e.g. is sufficient)*	M1 A1	**[2]**
	(c)	constant probability of decay (per unit time) of a nucleus cannot predict which particular nucleus will decay next	B1 B1	**[2]**

Q4.

7	(a)	β(-decay)	B1	[1]
	(b)	γ(-decay) *either* any two of *Z*, *N* and *A* do not change *or* it is loss of energy only *or* it is an electromagnetic wave Allow 'α(-decay) as change of 4 in the nucleon number cannot be shown on the diagram' Do not give credit for a 'bald' α(-decay)	B1 B1 (B2)	[2]

Q5.

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7 **(a)** α-particle: *either* helium nucleus *or* contains 2 protons + 2 neutrons
or $^{4}_{2}He$ B1

β-particle: *either* electron *or* $^{0}_{-1}e$ B1

α speed < β speed (1)
α discrete values of speed/energy, β continuous spectrum (1)
either α ionising power >> β ionising power
or α range << β range (1)
α positive, β negative *(only if first two B marks not scored)* (1)
α mass > β mass *(only if first two B marks not scored)* (1)
(any two sensible pairs of statements relevant to differences,
– do not allow statements relevant to only α or β, 1 each, max 2) B2 [4]

(b) **(i)** $^{236}_{92}U \rightarrow {}^{232}_{90}Th$ M1
$+ {}^{4}_{2}He$ A1 [2]

(ii) **1.** correct position for U at $Z = 92$, $N = 145$ B1
2. correct position for Np relative to U i.e. $Z + 1$ and $N - 1$ B1 [2]

Q6.

8 **(a)** rate of decay / activity / decay (of nucleus) is not affected by external factors / environment / surroundings ..... B2 [2]
(If states specific factor(s), rather than giving general statement above, then give 2 marks for two stated factors, but 1 mark only if one factor stated)

(b) **(i)** gamma / γ ..... B1 [1]

(ii) alpha / α ..... B1 [1]

(iii) gamma / γ ..... B1 [1]

(iv) beta / β ..... B1 [1]

Q7.

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7 **(a)** nuclei/atoms with same proton number/atomic number B1
nuclei/atoms contain different numbers of neutrons/different atomic mass ..... B1 [2]

(b) **(i)** 92 ..... A1 [1]

(ii) 146 ..... A1 [1]

(c) **(i)** mass = $238 \times 1.66 \times 10^{-27}$ C1
$= 3.95 \times 10^{-25}$ kg ..... A1 [2]

(ii) volume = $\frac{4}{3}\pi \times (8.9 \times 10^{-15})^3$ $(= 2.95 \times 10^{-42})$ C1
density = $(3.95 \times 10^{-25})/(2.95 \times 10^{-42})$
$= 1.3 \times 10^{17}$ kg m^{-3} ..... A1 [2]

(d) nucleus contains <u>most</u> of mass of atom B1
either nuclear diameter/volume <u>very much</u> less than that of atom
or atom is mostly (empty) space ..... B1 [2]

Q8.

7 **(a)** **(i)** *either* helium <u>nucleus</u>
or contains 2 protons and 2 neutrons ..... B1 [1]

(ii) e.g. range is a few cm in air/sheet of <u>thin</u> paper
speed up to 0.1 *c*
causes dense ionisation in air
positively charged or deflected in magnetic or electric fields
(*any two, 1 each to max 2*) ..... B2 [2]

(b) **(i)** $^4_2\alpha$ B1
either $^1_1$p *or* $^1_1$H ..... B1 [2]

(ii) **1** initially, α-particle must have some kinetic energy ..... B1 [1]

(ii) **2** 1.1 MeV = $1.1 \times 1.6 \times 10^{-13} = 1.76 \times 10^{-13}$ J C1
$E_K = \frac{1}{2}mv^2$ C1
$1.76 \times 10^{-13} = \frac{1}{2} \times 4 \times 1.66 \times 10^{-27} \times v^2$ C1
$v = 7.3 \times 10^6$ m s^{-1} ..... A1 [4]
use of 1.67×10^{-27} kg for mass is a maximum of 3/4

Q9.

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7	(a)	(i)	*either* helium nucleus *or* particle containing two protons and two neutrons	B1	[1]
		(ii)	allow any value between 1 cm and 10 cm	B1	[1]
	(b)	(i)	energy = $(8.5 \times 10^{-13})/(1.6 \times 10^{-13})$ = 5.3 MeV	M1 A0	[1]
		(ii)	number = $(5.3 \times 10^{6})/31$ = 1.7×10^{5} (*allow 2 s.f. only*)	C1 A1	[2]
		(iii)	number per unit length = (1.7×10^{5}) / **(a)(ii)** correct numerical value correct unit	 A1 B1	[2]

Q10.

7	(a)	(i)	2 protons and 2 neutrons	B1	[1]
		(ii)	e.g. positively charged 2*e* mass 4u constant energy absorbed by thin paper *or* few cm of air (3 cm → 8 cm) (*not low penetration*) highly ionizing deflected in electric/magnetic fields (*One mark for each property, max 2)*	B2	[2]
	(b)		mass-energy is conserved difference in mass 'changed' into a form of energy energy in the form of kinetic energy of the products / γ-radiation photons / e.m. radiation	B1 B1 B1	[3]

Q11.

7	(a)		W = 1 and X = 0	A1	[1]
			Y = 2	A1	[1]
			Z = 55	A1	[1]
	(b)		explanation in terms of mass – energy conservation energy released as gamma or photons or kinetic energy of products or em radiation	B1 B1	[2]

Q12.

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7	(a)	thin paper reduces count rate hence α	B1	
		addition of 1 cm of aluminium causes little more count rate reduction hence only other radiation is γ	B1	[2]
	(b)	magnetic field perpendicular to direction of radiation	B1	
		look for a count rate in expected direction / area if there were negatively charged radiation present. If no count rate recorded then β not present.	B1	[2]

Q13.

7	(a)	the majority/most went straight through or were deviated by small angles	B1	
		a very small proportion/a few were deviated by large angles	B1	
		small angles described as < 10° and large angles described as >90°	B1	[3]
	(b)	most of the atom is empty space/nucleus very small compared with atom	B1	
		mass and charge concentrated in (very small) nucleus	B1	
		correct links made with statements in **(a)**	B1	[3]

Q14.

7	(a)	(i)	$W = 206$ and $X = 82$	A1	
			$Y = 4$ and $Z = 2$	A1	[2]
		(ii)	mass-energy is conserved	B1	
			mass on rhs is less because energy is released	B1	[2]
	(b)		not affected by external conditions/factors/environment or two examples temperature and pressure	B1	[1]

Q15.

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7	(a)	(i)	nucleus contains 92 protons	B1	
			nucleus contains 143 neutrons (missing 'nucleus' 1/2)	B1	
			outside / around nucleus 92 electrons	(B1)	
			most of atom is empty space / mass concentrated in nucleus	(B1)	
			total charge is zero	(B1)	
			diameter of atom ~ 10^{-10} m or size of nucleus ~ 10^{-15} m	(B1)	
			any two of (B1) marks		[4]
		(ii)	nucleus has same number / 92 protons	B1	
			nuclei have 143 and 146 neutrons (missing 'nucleus' 1/2)	B1	[2]
	(b)	(i)	$Y = 35$	A1	
			$Z = 85$	A1	[2]
		(ii)	mass-energy is conserved in the reaction	B1	
			mass on rhs of reaction is less so energy is released		
			explained in terms of $E = mc^2$	B1	[2]

Q16.

8	(a)		shows nucleon number as 220	B1
			shows proton number as 87	B1 [2]
	(b)		shows products as $^{4}_{2}He$ OR $^{4}_{2}\alpha$	B1
			and $^{216}_{85}At$ ....(allow e.c.f. from (a))	B1 [2]

Q17.

6	(a)	(i)	26 protons.....	B1	
		(ii)	30 neutrons.....	B1	[2]
	(b)	(i)	mass = $56 \times 1.66 \times 10^{-27}$	C1	
			(allow $\times 1.67 \times 10^{-27}$ but 0/2 for use of 26 or 30)		
			$= 9.3 \times 10^{-26}$ kg.....	A1	
		(ii)	density = mass/volume where volume = $4/3 \times \pi \times r^3$.....	C1	
			$= (9.3 \times 10^{-26})/(4/3 \times \pi \times \{5.7 \times 10^{-15}\}^3)$		
			$= 1.2 \times 10^{17}$ kg m^{-3}	A1	[4]
	(c)		nucleus occupies only very small fraction of <u>volume of atom</u>		
			or 'lot of empty space inside atom'.....	B1	
			(do not allow spacing between atoms)		
			any further good physics e.g. nuclear material is very dense	B1	[2]

Q18.

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7	(a) (i)	nucleus is small	**M1**		
		in comparison to size of atom	**A1**	**[2]**	
	(ii)	nucleus is massive/heavy/dense	**B1**		
		and charged (allow to be scored in **(i)** or **(ii)**)	**B1**	**[2]**	
	(b) (i)	symmetrical path and deviation correct w.r.t. position of nucleus	**B1**		
		deviation less than in path AB	**B1**		
	(ii)	deviation > 90° and in correct direction	**B1**	**[3]**	

Q19.

7	(a)	most α-particles deviated through small angles (*accept 'undeviated'*)	B1	
		few α-particles deviated through angles greater than 90°	B1	[2]
	(b) (i)	allow 10^{-9} m $\rightarrow$ 10^{-11} m	B1	[1]
	(ii)	allow 10^{-13} m $\rightarrow$ 10^{-15} m (*if **(i)** and **(ii)** out of range but **(ii)** = 10^{-4} **(i)**, then allow 1 mark*) (*if no units or wrong units but **(ii)** = 10^{-4} **(i)**, then allow 1 mark*)	B1	[1]

Q20.

8	(a)	nucleus has constant probability of decay per unit time / in a given time (*allow 1 mark for 'cannot predict which nucleus will decay next'*)	M1 A1	[2]
	(b) (i)	count rate / activity decreases	B1	[1]
	(ii)	count rate fluctuates / is not smooth	B1	[1]
	(c)	*either* the (decay) curves are similar / same *or* curves indicate same half-life	B1	[1]

Q21.

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7 **(a)** deviation shown correctly ..... B1 [1]

(b) smaller deviation (not zero deviation) M1
acceptable path wrt position of N ..... A1 [2]

(c) the nucleus is (very) small M1
in comparison to the atom ..... A1 [2]
(special *case: 'atom is mostly empty space' scores 1 mark*)

(d) deviation depends on charge on the nucleus / N / electrostatic repulsion B1
same charge so no change in deviation ..... B1 [2]

[Total: 7]

Q22.

7 **(a)** *either* forms of same element
or atoms / nuclei with same number of protons M1
atoms / nuclei contain different numbers of neutrons ..... A1 [2]
(*use of 'element' rather than atoms / nuclei scores max 1 mark*)

(b) **(i)** decay is not affected by environmental factors ..... B1 [1]
(*allow two named factors*)

(ii) *either* time of decay (of a nucleus) cannot be predicted
or nucleus has constant probability in a given time ..... B1 [1]

(c) $^{185}_{75}\text{Re}$ B1
either $^{0}_{-1}\text{e}$ *or* $^{0}_{-1}\beta$ ..... B1 [2]

[Total: 6]

Q23.

7 **(a)** *either* different forms of same element
or nuclei have same number of protons M1
different numbers of neutrons (in the nucleus) A1 [2]

(b) **(i)** proton number conserved B1
nucleon number conserved B1
mass-energy conserved B1 [3]

(ii) **1.** $Z = 36$ A1 [1]
2. $x = 3$ A1 [1]

Q24.

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7 (a) (i) most α-particles were deviated through small angles B2 [2]
(*allow 1 mark for 'straight through' / undeviated*)

(ii) small fraction of α-particles deviated through large angles M1
greater than 90° (allow rebound back) A1 [2]

(b) e.g. β-particles have a range of energies
β-particles deviated by (orbital) electrons
β-particle has (very) small mass
(*any two sensible suggestions, 1 each, max 2*) B2 [2]

Do not allow β-particles have negative charge or β-particles have high speed

Q25.

9 (a) nucleus emits α-particles or β-particles and/or γ-radiation B1
to form a different / more stable nucleus B1 [2]

(b) (i) fluctuations in count rate (not 'count rate is not constant') B1 [1]

(ii) no effect B1 [1]

(iii) if the source is an α-emitter B1
either α-particles stopped within source (and gain electrons)
or α-particles are helium nuclei B1 [2]

allow 1/2 for 'parent nucleus gives off radiation to form daughter nucleus'

Q26.

7 (a) nuclei with the same number of protons B1
and a different number of neutrons B1 [2]

(b) (i) (mass + energy) (taken together) is conserved (B1)
momentum is conserved (B1)
one point required max. 1 B1 [1]

(ii) $a = 1$ and $b = 0$ B1
$x = 56$ B1
$y = 92$ B1 [3]

(c) proton number = 90 B1
nucleon number = 235 B1 [2]

Q27.

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7 **(a)** **(i)** the half life / count rate / rate of decay / activity is the same no matter what external factors / environmental factors **or** two named factors such as temperature and pressure changes are applied B1 [1]

(ii) the observations of the count rate / count rate / rate of decay / activity / radioactivity during decay shows variations / fluctuations B1 [1]

(b)

property	α-particle	β-particle	γ-radiation
charge	**(+)2*e***	**−*e***	0
mass	4*u*	**9.11×10^{-31} kg**	0
speed	**0.01 to 0.1 *c***	up to 0.99 *c*	***c***

one mark for each correct line B3 [3]

(c) collision with molecules B1
causes ionisation (of the molecule) / electron is removed B1 [2]

Q28.

6 **(a)** **(i)** greater deflection M0
greater electric field / force on α-particle A1 [1]

(ii) greater deflection M0
greater electric field / force on α-particle A1 [1]

(b) **(i)** *either* deflections in opposite directions M1
because oppositely charged A1
or β less deflection (M1)
β has smaller charge (A1) [2]

(ii) α smaller deflection M1
because larger mass A1 [2]

(iii) β less deflection because higher speed B1 [1]

(c) *either* $F = ma$ and $F = Eq$ *or* $a = Eq / m$ C1
ratio = *either* $\frac{(2 \times 1.6 \times 10^{-19}) \times (9.11 \times 10^{-31})}{(1.6 \times 10^{-19}) \times 4 \times (1.67 \times 10^{-27})}$
or [2*e* × 1 / 2000 u] / [*e* × 4u] C1

ratio = 1 /4000 *or* 2.5×10^{-4} *or* 2.7×10^{-4} A1 [3]

Q29.

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6 **(a)** 92 protons in the nucleus and 92 electrons around nucleus B1
143 neutrons (in the nucleus) B1 [2]

(b) **(i)** α-particle travels short distance in air B1 [1]

(ii) very small proportion in backwards direction / large angles B1
majority pass through with no /small deflections B1
either most of mass is in very small volume (nucleus) and is charged or most of atom is empty space B1 [3]

(c) $I = Q / t$ C1
$n/t = (1.5 \times 10^{-12}) / (2 \times 1.6 \times 10^{-19})$ C1
$n/t = 4.7 \times 10^{6}\,s^{-1}$ A1 [3]

Q30.

7 **(a)** ${}^{3}_{2}He + {}^{3}_{2}He \rightarrow {}^{4}_{2}He + 2\,{}^{1}_{1}p + Q$
A numbers correct (**4** and **1**) B1
Z numbers correct (**2** and **1**) B1 [2]

(b) both nuclei have 2 protons B1
the two isotopes have 1 neutron and two neutrons B1 [2]
[allow 1 for 'same number of protons but different number of neutrons']

(c) proton number and neutron number B1
energy – mass B1
momentum B1 [2]

(d) **(i)** γ radiation B1 [1]

(ii) product(s) must have kinetic energy B1 [1]

(e) 13.8 MeV = $13.8 \times 1.6 \times 10^{-19} \times 10^{6}$ ($= 2.208 \times 10^{-12}$) C1
$60 = n \times 13.8 \times 1.6 \times 10^{-13}$
$n = 2.7(2) \times 10^{13}\ s^{-1}$ A1 [2]

Q31.

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6	(a)	(i)	electron	B1	[1]
		(ii)	any **two:** can be deflected by electric and magnetic fields or negatively charged / absorbed by few (1 – 4) mm of aluminum / 0.5 to 2 m or metres for range in air / speed up to 0.99c / range of speeds / energies	B2	[2]
		(iii)	decay occurs and cannot be affected by external / environmental factors or two stated factors such as chemical / pressure / temperature / humidity	B1	[1]
	(b)		3 and 0 for superscript numbers 2 and –1 for subscript numbers	B1 B1	[2]
	(c)		energy = $5.7 \times 10^3 \times 1.6 \times 10^{-19}$ (= 9.12×10^{-16} J)	C1	
			$v^2 = \frac{2 \times 9.12 \times 10^{-16}}{9.11 \times 10^{-31}}$	C1	
			$v = 4.5 \times 10^7$ m s^{-1}	A1	[3]
	(d)		both have 1 proton and 1 electron 1 neutron in hydrogen-2 and 2 neutrons in hydrogen-3 (special case: for one mark 'same number of protons / atomic number different number of neutrons')	B1 B1	[2]

Q32.

7	(a)	(i)	the direction of the fields is the same OR fields are uniform OR constant electric field strength OR $E = V / d$ with symbols explained	B1	[1]
		(ii)	reduce p.d. across plates increase separation of plates	B1 B1	[2]
		(iii)	α opposite charge to β (as deflection in opposite direction) β has a range of velocities OR energies (as different deflections) and α all have same velocity OR energy (as constant deflection) α are more massive (as deflection is less for greater field strength)	B1 B1 B1	[3]
	(b)		$W = 234$ and $X = 90$ $Y = 4$ and $Z = 2$	B1 B1	[2]
	(c)		$A = 32$ and $B = 16$ and $C = 0$ and $D = -1$	B1	[1]

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