Question	Answer	Marks	Guidance
1 (a)	antiproton; antiparticle; **–1 (or –*e*)** neutrino; **particle; 0** neutron; **particle;** 0 positron; **antiparticle; +1(or +*e*)**	3	There are six spaces to fill; the answers are shown here in bold type. All 6 correct: 3 marks 4 or 5 correct: 2 marks 2 or 3 correct: 1 mark
1 (b) (i)	they carry opposite charges (+*e* and –*e*)	1	The magnetic field therefore forces them in opposite directions.
1 (b) (ii)	they lose kinetic energy gradually as they travel along their paths	1	'The slower it went, the more it would bend' (passage). Slower charged particles are deflected more easily by a magnetic field.
1 (b) (iii)	Relevant points include: • the speed is greater where the track is less curved • the straighter track must therefore be before the particle met the plate • the direction of the curve shows that the charge is positive • the track must therefore be due to a positron	3	'… he discovered a beta particle that slowed down but bent in the opposite direction to all the other beta trails …' (passage).
2 (a)	90 protons 139 neutrons and 90 electrons	1 1	Proton number $Z = 90$ Number of neutrons = 229 – 90 Number of electrons = Z
2 (b)	$X = 90$ Y = any value between 212 and 252 $Z = 90$	1 1 1	This is still thorium, and here X is used to represent the proton number. In a **different** isotope, the nucleon number cannot be 229. The number of electrons is unchanged.
3 (a)	18 protons 19 neutrons	1 1	Proton number $Z = 18$ Number of neutrons = 37 – 18
3 (b)	charge = +2 or +2*e* $Q = 2 \times 1.6 \times 10^{-19} = 3.2 \times 10^{-19}$ C	1 1	2 electrons have been removed, so the ion's charge is positive.
3 (c) (i)	neutron	1	$Q = 0$ for a neutron, so $\frac{Q}{m}$ is also zero
3 (c) (ii)	electron	1	The electro⁻'s small mass gives it the largest $\frac{Q}{m}$.
3 (d)	$(\%) = \frac{16 \times 9.11 \times 10^{-31}}{37 \times 1.67 \times 10^{-27}} \times 100$ $= 2.4 \times 10^{-2}$ %	2 1	Marks are for correct nuclear mass, and for correct substitution of values in rest of the equation. Remember to multiply by 100 to get a percentage.

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4 (a)	number of protons = number of electrons (e.g. 13) number of neutrons = (28 – number of protons) (e.g. 15)	1 1	Neutral atoms have an equal number of protons and electrons. There could have been 14 protons and 14 neutrons!
4 (b) (i)	nuclei have same number of protons	1	This answer follows directly from the definition of isotopes.
4 (b) (ii)	but a different number of neutrons, or nucleons	1	
4 (b) (iii)	$\frac{Q}{m} = \frac{92 \times 1.60 \times 10^{-19}}{236 \times 1.67 \times 10^{-27}}$ $= 3.7 \times 10^{7}$ C kg^{-1}	1	The mark is for correct substitution of charge and mass values and a correct calculation.
4 (b) (iv)	95	1	The number of protons and neutrons (given by the mass numbers for the nuclei) on each side is the same.
5 (a)	*X* = 225 *Y* = 88	1 1	Nucleon numbers must balance in the decay, and α is a helium nucleus with *A* = 4. Proton numbers must also balance, and *Z* = 2 for the α particle.
5 (b)	ratio ($= \frac{225}{4}$) = 56	1	The answer is a ratio of two masses and has **no unit**.
6 (a) (i)	a helium nucleus (or a doubly-ionised helium atom) Properties: • charge +2*e* • mass ≈ 4 units	1 2	(i) tests your factual knowledge. An α particle consists of 2 protons and 2 neutrons, giving these charge and mass values.
6 (a) (ii)	$^{215}_{85}\text{At} \rightarrow {}^{211}_{83}\text{Bi} + \alpha$	2	1 mark for writing $^{211}_{83}$Bi as the product nucleus and the second mark for the completed reaction equation.
6 (b) (i)	Relevant points include: • a neutron changes into a proton • the proton remains in the nucleus • a high energy electron (β− particle) is emitted from the nucleus • an antineutrino is also emitted • the nucleus becomes more stable	3	Electrons do not reside in the nucleus; the β^- particle is formed at the instant of decay. The antineutrino is necessary to explain the range of energies of the β^- particles that are emitted.
6 (b) (ii)	$^{99}_{42}\text{Mo} \rightarrow {}^{99}_{43}\text{Tc} + \beta^- + \bar{\nu}$	2	1 mark for inserting the missing values of 99 and 43, and 1 mark for including the antineutrino. In β^- decay *A* stays the same but *Z* increases by 1 (since a neutron changes into a proton).
7 (a) (i)	9.11×10^{-31} kg	1	The β^+ particle is a positron, with the same rest mass as an electron.

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7 (a) (ii)	$f\ (= \frac{c}{\lambda}) = \frac{3.00 \times 10^{8}}{8.30 \times 10^{-13}}$ $(= 3.61 \times 10^{20}$ Hz) $E\ (= hf) = 6.63 \times 10^{-34} \times 3.61 \times 10^{20}$ (= 2.4 × 10−13 J)	1 1 1	All 3 marks would be available for direct use of $E = (\frac{hc}{\lambda})$, but you must show your working whatever method you choose.
7 (a) (iii)	$E = \frac{2.39 \times 10^{-13}}{1.60 \times 10^{-13}}$ = 1.5 MeV	1 1	Since 1 eV = 1.60×10^{-19} J, it follows that 1 MeV is 10^{6} times larger.
7 (b)	weak interaction	1	Always involved in β decay.
8 (a) (i)	electron	1	A positron is a ‘positive electron’, having the same mass and equal but opposite charge.
8 (a) (ii)	they annihilate, or destroy each other forming two gamma rays (or photons)	1 1	2 photons are always needed when annihilation takes place. ‘Forming **energy**’ would not be enough for the second mark.
8 (b)	energy released = 2 × 0.51 = 1.02 MeV $= 1.02 \times 1.60 \times 10^{-13} = 1.6 \times 10^{-13}$ J	1 1	The antiparticle must have the same rest mass as the particle. The energy released is the total of the rest energies. The energy released could be greater than this if the particles were to meet with a significant amount of kinetic energy, so the value calculated is the minimum energy released.
9 (a) (i)	they annihilate, or destroy each other, or form two photons	1	This is straightforward annihilation of a particle and its antiparticle.
9 (a) (ii)	the energy associated with the rest masses must be added	1	**Total** energy includes both the kinetic energy and the rest mass energy of the two colliding particles. Photons have no rest mass.
9 (b)	There are 3 possibilities: the particles produced could • be more numerous • be more massive • have greater kinetic energy	any 2	Annihilation can produce particles other than photons (e.g. muons) when the colliding particles have a total energy greater than the rest masses of the particles that are produced.
10	weak interaction	1	
11 (a)	γ photon/electromagnetic force	2	1 mark for naming the exchange particle and the second mark for the corresponding interaction.

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11 (b)	Possible roles are: • transfers energy • transfers momentum • transfers force • (sometimes) transfers charge	any 2	One mark for each named role.
12	A high energy γ photon is required	1	Energy must be sufficient to create at least the total rest masses of the particles produced.
	It is converted into a particle and its antiparticle	1	This occurs in the vicinity of another particle, such as a nucleus or an electron.
	Suitable example named, such as: • proton + antiproton • electron + positron	1	Only one example is needed.