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 \(^4\text{He}\) or as \(^4\alpha\) .............................................. 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 \(A = A_\alpha\) and with \(Z = (Z_\alpha + 1)\) .................................................. 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 [2]

Q4.

7 (a) \(\beta^+\) (decay) .................................................. B1 [1]

(b) \(\gamma\) (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)

Q5.
7 (a) \( \alpha \)-particle: either helium nucleus or contains 2 protons + 2 neutrons
\[ \text{or } {^4}_2\text{He} \]
\( \beta \)-particle: either electron or \( {^0}_{-1}\text{e} \)
\( \alpha \) speed < \( \beta \) speed (1)
\( \alpha \) discrete values of speed/energy, \( \beta \) continuous spectrum (1)
either \( \alpha \) ionising power >> \( \beta \) ionising power
or \( \alpha \) range << \( \beta \) range (1)
\( \alpha \) positive, \( \beta \) negative (only if first two B marks not scored) (1)
\( \alpha \) mass > \( \beta \) 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 \( \alpha \) or \( \beta \), 1 each, max 2) B2 [4]

(b) (i) \( ^{235}_{92}\text{U} \rightarrow ^{233}_{90}\text{Th} \)
\( + {^4}_2\text{He} \) 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 / \( \gamma \) ................................................................. B1 [1]
(ii) alpha / \( \alpha \) .............................................................................. B1 [1]
(iii) gamma / \( \gamma \) .............................................................................. B1 [1]
(iv) beta / \( \beta \) .............................................................................. B1 [1]

Q7.
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
      = $3.95 \times 10^{-26}$ kg .................................................................................. A1 [2]

(ii) volume = $\frac{4}{3} \pi (8.9 \times 10^{-15})^3$ (= $2.95 \times 10^{-45}$) ........................................ C1
density = $(3.95 \times 10^{-26})(2.95 \times 10^{-45})$
         = $1.3 \times 10^{-7}$ kg m$^{-3}$ ........................................................................ A1 [2]

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

Q8.

7. (a) (i) Either helium nucleus
or contains 2 protons and 2 neutrons ................................................................. B1 [1]

(ii) e.g. range is a few cm in air/sheet of thin 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) $\frac{1}{2}^a$ .................................................................................................................. B1 [2]
either $^p$ or $^1H$ ...................................................................................................... B1 [2]

(ii) 1 initially, $\alpha$-particle must have some kinetic energy ........................................ B1 [1]

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

Q9.
Q10.

7 (a) (i) \( \text{either helium nucleus or particle containing two protons and two neutrons} \)  
\( \text{B1 [1]} \)

(ii) \( \text{allow any value between 1 cm and 10 cm} \)  
\( \text{B1 [1]} \)

(b) (i) \( \text{energy} = \frac{(8.5 \times 10^{-13})/(1.6 \times 10^{-19})}{5.3 \text{ MeV}} = 5.3 \text{ MeV} \)  
\( \text{M1 [1]} \)

(ii) \( \text{number} = \frac{(5.3 \times 10^9)/31}{1.7 \times 10^5} = \text{allow 2 s.f. only} \)  
\( \text{C1 [1]} \)

(iii) \( \text{number per unit length} = \frac{(1.7 \times 10^5)}{\text{(a)(ii)}} \)  
\( \text{correct numerical value} \)  
\( \text{A1 [2]} \)

\( \text{correct unit} \)  
\( \text{B1 [2]} \)

Q11.

7 (a)  
\( \text{2 protons and 2 neutrons} \)  
\( \text{B1 [1]} \)

(ii) \( \text{e.g. positively charged 2e mass 4u constant energy absorbed by thin paper or few cm of air (3 cm \( \rightarrow \) 8 cm) \( \text{not low penetration} \) highly ionizing deflected in electric/magnetic fields \( \text{One mark for each property, max 2} \) \)  
\( \text{B2 [2]} \)

(b) \( \text{mass-energy is conserved} \)  
\( \text{B1} \)

\( \text{difference in mass 'changed' into a form of energy} \)  
\( \text{B1} \)

\( \text{energy in the form of kinetic energy of the products} \)  
\( \text{\( \gamma \)-radiation} \)  
\( \text{photons / e.m. radiation} \)  
\( \text{B1 [3]} \)

Q12.

7 (a) \( W = 1 \) and \( X = 0 \)  
\( Y = 2 \)  
\( Z = 55 \)  
\( \text{A1 [1]} \)

(b) \( \text{explanation in terms of mass - energy conservation} \)  
\( \text{energy released as gamma or photons or kinetic energy of products or em radiation} \)  
\( \text{B1 [2]} \)
7 (a) thin paper reduces count rate hence α
addition of 1 cm of aluminium causes little more count rate reduction hence only other radiation is γ

(b) magnetic field perpendicular to direction of radiation
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.

Q13.

7 (a) the majority/most went straight through
or were deviated by small angles

a very small proportion/a few were deviated by large angles
small angles described as < 10° and large angles described as >90°

(b) most of the atom is empty space/nucleus very small compared with atom
mass and charge concentrated in (very small) nucleus
correct links made with statements in (a)

Q14.

7 (a) (i) \( W = 206 \) and \( X = 82 \)
\( Y = 4 \) and \( Z = 2 \)

(ii) mass-energy is conserved
mass on rhs is less because energy is released

(b) not affected by external conditions/factors/environment
or two examples temperature and pressure

Q15.
7 (a) (i) nucleus contains 92 protons nucleus contains 143 neutrons (missing 'nucleus' 1/2) outside / around nucleus 92 electrons most of atom is empty space / mass concentrated in nucleus total charge is zero diameter of atom ~ 10^{-10} m or size of nucleus ~ 10^{-15} m any two of (B1) marks B1 [4]

(ii) nucleus has same number / 92 protons nuclei have 143 and 146 neutrons (missing 'nucleus' 1/2) B1 [2]

(b) (i) \( Y = 35 \)
\( Z = 85 \) A1 [2]

(ii) mass-energy is conserved in the reaction 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 shows proton number as 87 B1 [2]

(b) shows products as \(^4\text{He}\) OR \(^4\text{He}\) \(^2\text{He}\) and \(^{26}\text{Fe}\) \(\ldots\) (allow e.c.f. from (a)) B1 [2]

Q17.

6 (a) (i) 26 protons 30 neutrons B1 [2]

(b) (i) mass = 56 \times 1.66 \times 10^{-27} \text{ kg} (allow x 1.67 \times 10^{-27} but 0/2 for use of 26 or 30) = 9.3 \times 10^{-26} \text{ kg} A1

(ii) density = mass/volume where volume = 4/3 \pi x r^3 = (9.3 \times 10^{-26})/(4/3 \pi x (5.7 \times 10^{-13})^3) = 1.2 \times 10^{17} \text{ kg m}^{-3} A1 [4]

(c) nucleus occupies only very small fraction of volume of atom or 'lot of empty space inside atom' (do not allow spacing between atoms) any further good physics e.g. nuclear material is very dense B1 [2]

Q18.
7 (a) (i) nucleus is small in comparison to size of atom M1
(ii) nucleus is massive/heavy/dense 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
(ii) deviation > 90° and in correct direction B1 [3]

Q19.

7 (a) most α-particles deviated through small angles B1
(accept ‘undeviated’)
few α-particles deviated through angles greater than 90° B1 [2]

(b) (i) allow 10^{-9} m → 10^{-11} m B1 [1]
(ii) allow 10^{-13} m → 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 M1
(allow 1 mark for ‘cannot predict which nucleus will decay next’) 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.
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) $^{185}_{76}$Re ................................................................. B1
either $\beta^-$ or $\beta^+$ ................................................. B1 [2]

[Total: 6]

Q23.

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

(b) (i) proton number conserved
nucleon number conserved
mass-energy conserved

(ii) 1. $Z = 36$
2. $x = 3$

A1 [1]
A1 [1]

Q24.
7. (a) (i) most α-particles were deviated through small angles 
(allow 1 mark for 'straight through'/undeviated) 

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

(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) 

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 to form a different / more stable nucleus 

(b) (i) fluctuations in count rate (not 'count rate is not constant') 

(ii) no effect 

(iii) if the source is an α-emitter 

either α-particles stopped within source (and gain electrons) 
or α-particles are helium nuclei 

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

Q26.

7. (a) nuclei with the same number of protons and a different number of neutrons 

(b) (i) (mass + energy) (taken together) is conserved momentum is conserved 

one point required max. 1 

(ii) a = 1 and b = 0 

x = 56 

y = 92 

(c) proton number = 90 
nucleon number = 235

Q27.
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)  

<table>
<thead>
<tr>
<th>property</th>
<th>α-particle</th>
<th>β-particle</th>
<th>γ-radiation</th>
</tr>
</thead>
<tbody>
<tr>
<td>charge</td>
<td>(+)2e</td>
<td>−e</td>
<td>0</td>
</tr>
<tr>
<td>mass</td>
<td>4u</td>
<td>9.11 × 10⁻³¹kg</td>
<td>0</td>
</tr>
<tr>
<td>speed</td>
<td>0.01 to 0.1c</td>
<td>up to 0.99c</td>
<td>c</td>
</tr>
</tbody>
</table>

one mark for each correct line B3 [3]

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

Q28.

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

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

(b) (i) either deflections in opposite directions because oppositely charged M1 A1 [1]

or β less deflection (M1)

β has smaller charge (A1) [2]

(ii) α smaller deflection because larger mass M1 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 \( (2 \times 1.6 \times 10⁻¹⁹) \times (9.11 \times 10⁻³¹) \) (M1)

\( (1.6 \times 10⁻¹⁹) \times 4 \times (1.67 \times 10⁻²³) \) (A1) [2]

or \( \frac{[2e \times 1/2000 u]}{|e \times 4u|} \) C1

ratio = 1 /4000 or \( 2.5 \times 10⁻⁴ \) or \( 2.7 \times 10⁻⁴ \) A1 [3]

Q29.
6  (a) 92 protons in the nucleus and 92 electrons around nucleus  
143 neutrons (in the nucleus)  

(b)  
(i) α-particle travels short distance in air  
(ii) very small proportion in backwards direction / large angles  
     majority pass through with no / small deflections  
     either most of mass is in very small volume (nucleus) and is charged or most of atom is  
     empty space  

(c) \[ J = \frac{Q}{t} \]  
\[ n/t = \frac{(1.5 \times 10^{-19})}{(2 \times 1.6 \times 10^{-19})} \]  
\[ n/t = 4.7 \times 10^8 \text{s}^{-1} \]

Q30.

7  (a) \( ^3\text{He} + ^3\text{He} \rightarrow ^4\text{He} + 2^{\text{He}} + Q \)  
   A numbers correct  (4 and 1)  
   Z numbers correct  (2 and 1)  

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

(c) proton number and neutron number  
   energy – mass  
   momentum  

(d)  
(i) γ radiation  
(ii) product(s) must have kinetic energy  

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

Q31.
Q32.

7 (a) (i) the direction of the fields is the same OR fields are uniform OR constant electric field strength OR $E = \frac{V}{d}$ with symbols explained

(b) $W = 234$ and $X = 90$
   $Y = 4$ and $Z = 2$

(c) $A = 32$ and $B = 16$ and $C = 0$ and $D = -1$