1 (a) Simple harmonic motion is defined as the motion of a particle about a fixed point such that its acceleration is proportional to its displacement from the fixed point and is always directed towards the point. [B1] [B1]

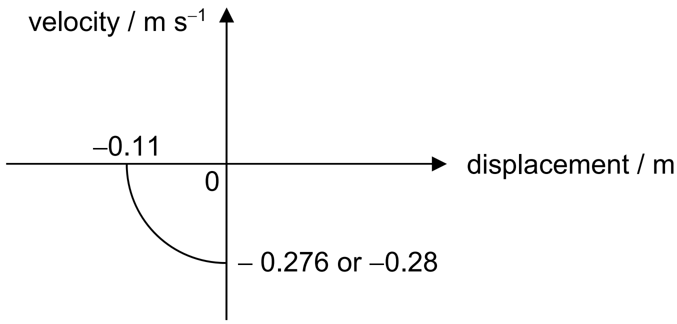
(b) 0.11 m [B1]

(c) $\omega = 2\pi f$

$= 2\pi \times 0.40$ [M1]

$= 2.51 = 2.5$ rad s^{-1} (2 s.f.) [A1]

(d)



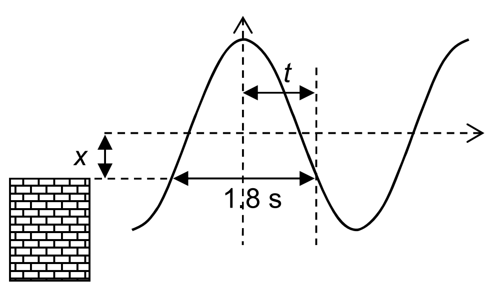
Graph in the correct quadrant, gradient at x-axis = ∞ and gradient at y-axis = 0. [B1]

Correct values at both intercepts ($-x_0 = -0.11$ m and $-v_{max} = -0.28$ m s^{-1}). [B1]

(e)

Period $T = \dfrac{1}{f} = \dfrac{1}{0.4} = 2.5$ s

Since the lamp is above the seawall for more than half the period (1.25 s), the equilibrium position of the lamp is above the seawall.



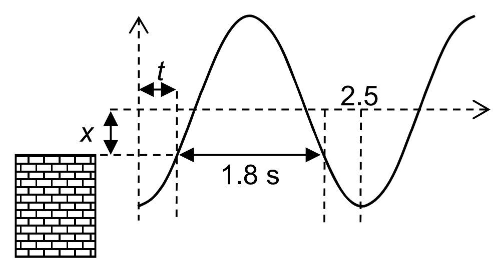
Time taken t for the lamp to go from its highest position to the top of the seawall

$t = \dfrac{1.8}{2} = 0.90$ s

$x = x_0 \cos \omega t$

$= 0.11 \cos (2.51 \times 0.90)$

$= -0.0699$ m



Time taken t for the lamp to go from its lowest position to the top of the seawall

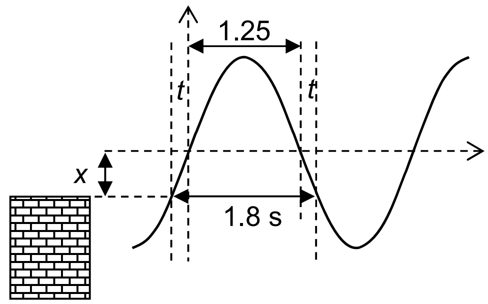
$t = \dfrac{2.5 - 1.8}{2} = 0.35$ s [M1]

$x = -x_0 \cos \omega t$

$= -0.11 \times \cos (2.51 \times 0.35)$ [M1]

$= -0.0701$ m [A1]

Alternatively,



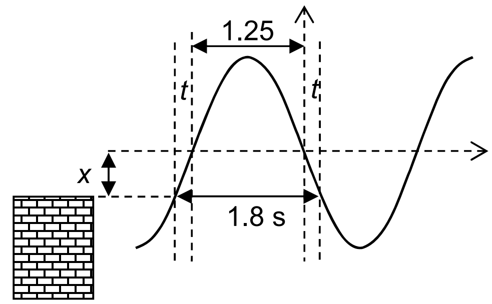
Time taken t for the lamp to go from equilibrium position to the top of the seawall

$t = \dfrac{1.8 - 1.25}{2} = 0.275$ s

$x = x_0 \sin \omega t$

$= 0.11 \cos [2.51 \times (1.25 + 0.275)]$

$= -0.0697$ m



Time taken t for the lamp to go from equilibrium position to the top of the seawall

$t = \dfrac{1.8 - 1.25}{2} = 0.275$ s [M1]

$x = -x_0 \sin \omega t$

$= -0.11 \cos (2.51 \times 0.275)$ [M1]

$= -0.0700$ m [A1]

2 (a) A progressive wave is one in which energy is transferred from one point to another without the transfer of matter. [B1]

A transverse wave is one in which the particles oscillate in a direction perpendicular to the direction of energy transfer. [B1]

(b) 4.0 s (1 d.p.) [B1]

(c) $\Delta\phi = (\Delta t / T) \times 2\pi$

$= (1.4 / 4.0) \times 2\pi$ OR $(7/20) \times 2\pi$ [M1]

$= 2.20 = 2.2$ rad (2 s.f.) [A1]

Ignore ± signs.

OR OR

$\Delta\phi = (\Delta t / T) \times 2\pi$

$= (2.6 / 4.0) \times 2\pi$ OR $(13/20) \times 2\pi$ [M1]

$= 4.08 = 4.1$ rad (2 s.f.) [A1]

(d) intensity $\propto$ (amplitude)^2

intensity $\propto 1/r$ (for 2D circular wavefront) [B1]

$\Rightarrow$ (amplitude)$^2 \propto 1/r$

$\Rightarrow r_Q A_Q^2 = r_P A_P^2$

From Fig. 2.2, $A_P = 2.0$ mm and $A_Q = 1.0$ mm,

$\Rightarrow r_Q\, 1.0^2 = (150) \times 2.0^2$ [M1]

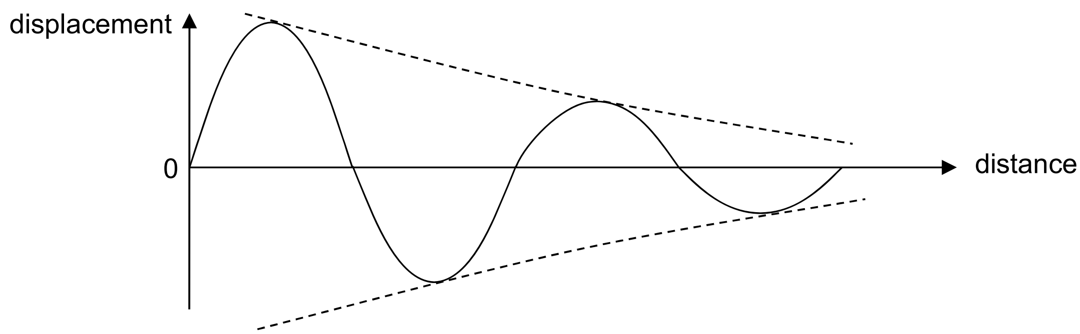
$\Rightarrow r_Q = 600$ mm [A0]

(e) $\Delta\phi = 2\pi \times (\Delta x / \lambda)$

$2.20 = 2\pi \times (600 - 150) / \lambda$ [M1]

$\lambda = 1286$ mm $= 1290$ or 1300 mm (2 s.f.) (allow ecf from (c)) [A1]

(f)



Graph shows amplitude of wave decreasing with distance. [B1]
Accept positive/negative sine/cosine graphs.

3 (a) (i) Coherent waves have a constant phase difference. [B1]

(ii) As the two transmitters emit coherent waves, a steady/observable two-source interference pattern is formed along the orbit. [B1]

When the waves meet in phase, a high intensity signal (or constructive interference) is detected by the satellite. When the waves meet in anti-phase, a low/zero intensity signal (or destructive interference) is detected by the satellite. either one [B1]

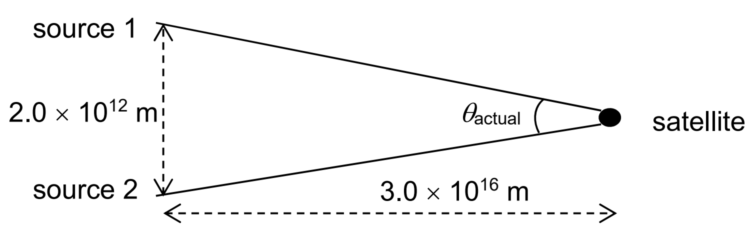
Since the satellite orbits at a constant speed and the "fringe separation" (or distance between successive maxima) is constant, the signals have a constant period (or vary periodically). [B1]

(iii) In 1 second, the satellite travels 8.0×10^3 m and receives 4 sets of variations in intensities, i.e. it has moved a distance of $4x$, where x is fringe separation.

$x = (8.0 \times 10^3)/ 4.0 = 2000$ m [C1]

$D = ax/\lambda$
$= (150)(2000)/(1.2)$ [M1]
$= 2.5 \times 10^5$ m [A1]

(b) (i)



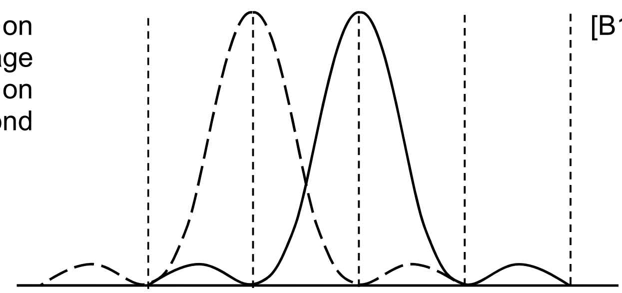
Actual angle subtended by the two distant sources at the telescope:
$\theta_{actual} \approx s / r$ (small angle approximation)
$= (2.0 \times 10^{12}) / (3.0 \times 10^{16})$
$= 6.7 \times 10^{-5}$ rad [M1]

Rayleigh criterion:
$\theta_{RC} = \lambda / b$ (where b, the "slit-width", is the size of the telescope dish)
$= 1.2 / 300$
$= 4.0 \times 10^{-3}$ rad [M1]

Since the angle subtended by the sources is smaller than that of Rayleigh criterion, the telescope cannot resolve these sources. [A1]

Accept circular aperture: $\theta_{RC} \approx 1.22\ \lambda / b = 1.22\ (1.2 / 300) = 4.9 \times 10^{-3}$ rad

(ii) Maxima of second image to lie on the first minima of the first image and maxima of first image lie on the first minima of the second image. [B1]



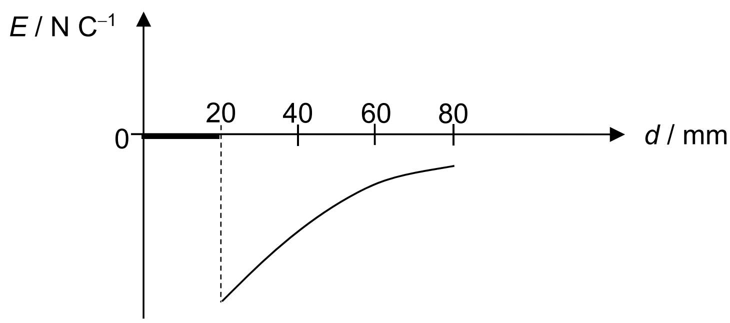
4 (a) (i) The electric field strength at a point is defined as the electric force exerted per unit positive charge (placed) at that point. [B1]

(ii) Magnitude of $E = Q / 4\pi\varepsilon_0 r^2$

$= (12 \times 10^{-9}) / (4\pi \times 8.85 \times 10^{-12} \times (20\times10^{-3})^2)$ [M1]

$= 2.70 \times 10^5 = 2.7 \times 10^5$ N C^{-1} (2 s.f.) [A1]

(iii)



0 to 20 mm: zero (must be drawn) [B1]

20 to 80 mm: curve with curve touching 20 mm, and non-zero at 80 mm [B1]

(iv) By the principle of conservation of energy,
gain in kinetic energy = loss of electric potential energy

$$KE_f - KE_i = \frac{qQ}{4\pi\varepsilon_0 r_i} - \frac{qQ}{4\pi\varepsilon_0 r_f}$$

$$KE_f - 0 = \frac{(-12\times10^{-9})(6.0\times10^{-9})}{4\pi(8.85\times10^{-12})}\left(\frac{1}{60\times10^{-3}} - \frac{1}{40\times10^{-3}}\right)$$ [M1]

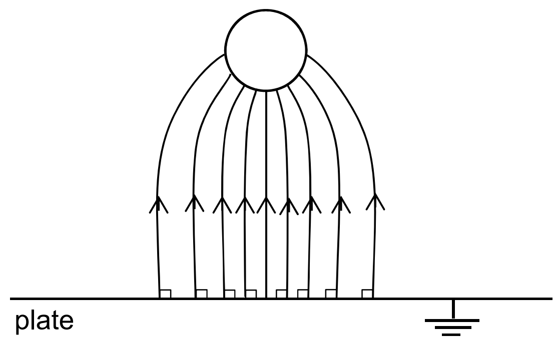
$$KE_f = 5.40\times10^{-6} = 5.4\times10^{-6} \text{ J (2 s.f.)}$$ [A1]

(iv) Area under the graph between d = 40 and 60 mm. [A1]
OR
Area between the graph and the distance axis, between d = 40 and 60 mm.

(b) The electric field lines [B2]

- cannot cross.
- indicated with arrow pointing from the plate towards the sphere.
- are perpendicular to the surfaces of the sphere and plate.
- are symmetrical about the vertical line through the centre of the sphere.
- are denser directly below the sphere and spread apart towards the edge of the plate (because the potential difference between the sphere and the plate is constant, the distance between sphere and plate is shortest below the sphere).

Deduct [1] for each mistake.



5 (a) (i)

$$B = \frac{\mu_0 I}{2\pi d}$$

$$= \frac{(4\pi \times 10^{-7})(2.0)}{2\pi(0.10)}$$ [M1]

$$= 4.0 \times 10^{-6} \text{ T}$$ [A0]

(b) (i) Faraday's law of electromagnetic induction states that the e.m.f. induced in a conductor is proportional to the rate of change of magnetic flux linkage. [B1]

(ii) At d = 20 cm from wire: $B = \frac{\mu_0 I}{2\pi d} = \frac{(4\pi \times 10^{-7})(2.0)}{2\pi(0.20)} = 2.0 \times 10^{-6}$ T [C1]

$$\langle E \rangle = -\frac{\Delta(NAB)}{\Delta t}$$

$$= -NA\frac{\Delta B}{\Delta t}$$

$$= -(50)(0.010 \times 0.010)\frac{(2.0 \times 10^{-6} - 4.0 \times 10^{-6})}{(0.40)}$$ [M1]

$$= 2.5 \times 10^{-8} \text{ V}$$ [A1]

(c) (i) By Lenz's law, the <u>induced current will flow in a way to oppose the decrease in magnetic flux density</u>. [M1]

Hence, the induced current flows in the <u>clockwise direction</u> (to reinforce the magnetic flux density into the paper). [A1]

OR OR

As the coil is being pulled away from the wire, by Lenz's law, the induced current in the coil flows in a way to oppose this motion. [M1]

Hence, the induced current must produce a net force which acts upwards by flowing clockwise (to produce a larger attractive force on the upper side and a smaller repulsive force on the lower side). [A1]

(ii) The induced current in the coil produces a magnetic force that opposes the coil's motion (or that pulls the coil towards the wire). [M1]

Therefore, an external force must be applied in the direction of motion to maintain a constant velocity (or applied to pull the coil away from the wire at a constant velocity). Hence, work has to be done by the external force. [A1]

OR

Since the coil moves at a constant speed, there is no change in kinetic energy. [M1]

Therefore, the electrical energy (or induced current) produced in the coil has to be produced by the work done by an external force. [A1]

6 (a) (i) When the white light is incident on the gas, photons with wavelengths that correspond to the energy difference between any two energy levels are absorbed by the atoms. [B1] During de-excitation, these photons are emitted in all directions. [B1] In the resulting spectrum, these wavelengths correspond to dark spectral lines on a coloured background. [B1]

(ii)

$$\Delta E_{12} = hf = h\frac{c}{\lambda_{12}}$$

$$\lambda_{12} = \frac{hc}{\Delta E_{12}}$$

$$= \frac{(6.63\times10^{-34})(3.00\times10^{8})}{[(-3.04)-(-5.14)]\times(1.60\times10^{-19})} \quad [M1]$$

$$= 592 \text{ nm (shown)} \quad [A0]$$

(iii)

$$\lambda_{13} = \frac{hc}{\Delta E_{13}}$$

$$= \frac{(6.63\times10^{-34})(3.00\times10^{8})}{[(-1.53)-(-5.14)]\times(1.60\times10^{-19})}$$

$$= 344 \text{ nm} \quad [M1]$$

Since wavelength of light corresponding to transition from E_1 to E_3 is already outside visible region, there is no need to test for transition from E_1 to E_4.

Hence, only one absorption spectral line, corresponding to the E_1 to E_2 transition, is observed. [A1]

OR

$$E_{max} = \frac{hc}{\lambda_{min}} = \frac{6.63\times10^{-34}\times3\times10^{8}}{400\times10^{-9}} = 4.97\times10^{-19}\text{ J} = 3.108\text{ eV}$$

$-5.14 + 3.108 = -2.03\text{ eV} < -1.53\text{ eV}$ [M1]

Since only level E_2 is attainable from level E_1, only one absorption spectral line, corresponding to the E_1 to E_2 transition, is observed. [A1]

(b) **(i)**

$$\text{KE} = \frac{p^2}{2m} = \frac{(h/\lambda)^2}{2m}$$

$$= \frac{(6.63\times10^{-34}/592\times10^{-9})^2}{2\times(9.11\times10^{-31})}$$ [M1]

$$= 6.88\times10^{-25}\text{ J}$$

$$= \frac{6.88\times10^{-25}}{1.6\times10^{-19}} = 4.30\times10^{-6}\text{ eV (3 s.f.)}$$ [A1]

(ii) **Advantages:** [B1]

- Higher resolution / higher magnification (up to 2 million times, due to shorter wavelengths used).
- Possible to view the three dimensional shape of an object.

Disadvantages: [B1]

- Expensive to buy and maintain.
- Space requirements are high – need a large room.
- Elaborate sample preparation (as it is often necessary to coat the specimen with a very thin layer of metal such as gold).
- Sample must be completely dry and placed in a vacuum (no living specimens.
- Not possible to observe colour. The image is only black & white. (Image is coloured artificially to give a better visual impression.)
- Energy of the electron beam is very high. Therefore sample is exposed to high radiation, which may not survive.

Reference: http://www.ivyroses.com/Biology/Techniques/light-microscope-vs-electron-microscope.php, http://www.newworldencyclopedia.org/entry/Electron_microscope

7 **(a)** **(i)** The gravitational potential at a point in a gravitational field is defined as the work done per unit mass by an external agent in bringing a small test mass from infinity to that point. [B1]

(ii) Since gravitational force is attractive in nature, the external force required to bring the small test mass from infinity to that point acts in the opposite direction to the displacement of the small test mass. Therefore, the work done by the external force is negative. By definition, gravitational potential is negative everywhere, except at infinity, where the gravitational potential is taken to be zero. [B1] [B1] [B1]

(iii) $\phi_C = \phi_{\text{due to } M_A} + \phi_{\text{due to } M_B}$

$$= \left(-G\frac{M_A}{r_A}\right) + \left(-G\frac{M_B}{r_B}\right)$$

$$= -\left(6.67\times10^{-11}\right)\times\left(\frac{5.00\times10^{31}}{1.86\times10^{12}}+\frac{3.00\times10^{31}}{1.31\times10^{12}}\right)$$ [M1]

$$= -3.32\times10^{9}\ \text{J kg}^{-1}\ \text{(3 s.f.) (shown)}$$ [A0]

(b) The minimum speed u is such that the asteroid's total energy at infinity is zero. Or, the loss in KE is equal to the gain in GPE. Hence, by the principle of conservation of energy,

initial energy at C = final energy at infinity OR gain in GPE = loss in KE

$$\frac{1}{2}mu_{\min}^2 + m\phi_C = 0 \qquad\qquad 0 - m\phi_C = \frac{1}{2}mu_{\min}^2 - 0$$ [M1]

$$u_{\min} = \sqrt{-2\phi_C}$$

$$= \sqrt{-2\times\left(-3.32\times10^{9}\right)}$$

$$= 8.15\times10^{4}\ \text{m s}^{-1}\ \text{(3 s.f.)}$$ [A1]

(c) **(i)** Correct tangent drawn at point C in Fig. 7.2 and coordinates stated, [B1]

$$|g_C| = \left|-\frac{d\phi}{dr}\right| = \text{gradient at C}$$

$$= \frac{\left(-2.000\times10^{9}\right)-\left(-4.400\times10^{9}\right)}{\left(30.00\times10^{11}\right)-\left(12.00\times10^{11}\right)}$$ (coordinates state to correct d.p.) [M1]

$$= \frac{2.400\times10^{9}}{18.00\times10^{11}}$$

$$= 1.333\times10^{-3}\ \text{N kg}^{-1}\ \text{(4 s.f.) or } 1.33\times10^{-3}\ \text{N kg}^{-1}\ \text{(3 s.f.)}$$ [A1]

Deduct [1] for out of range: $1.300\times10^{-3}\ \text{N kg}^{-1} \le |g_C| \le 1.400\times10^{-3}\ \text{N kg}^{-1}$

Deduct [1] for wrong d.p.

(ii) Indicated point D at (10.50×10^{11}, -4.325×10^{9}). [B1]

Since point D is on the line AB joining the centres of the stars, there is no component of gravitational field strength along the line XY. Hence, point D is at the position where the gradient of the potential–distance graph is zero or the graph is at the minimum turning point.

OR

Since point D is closest to both stars along the line XY, the gravitational potential is the lowest or most negative.

either one [B1]

(iii) From the graph, the distance CD = 9.50×10^{11} m. [B1]

Applying Pythagoras theorem,

$$AB = AD + DB$$

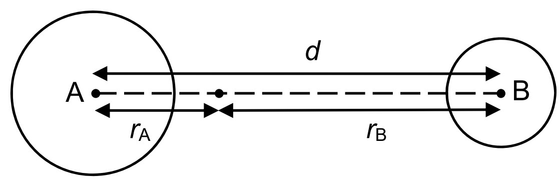
$$= \sqrt{\left(1.86\times10^{12}\right)^2 - \left(9.50\times10^{11}\right)^2} + \sqrt{\left(1.31\times10^{12}\right)^2 - \left(9.50\times10^{11}\right)^2}$$ [M1]

$$= \sqrt{2.557\times10^{24}} + \sqrt{8.136\times10^{23}}$$

$$= 1.60\times10^{12} + 9.02\times10^{11}$$

$$= 2.50\times10^{12} \text{ m (shown)}$$ [A0]

(d) The gravitational force of attraction between the two stars provides the centripetal force required to maintain the stars' circular motion about their common centre of rotation. (Accept "the centre of mass is the centre of rotation".) [B1]



$$G\frac{M_A M_B}{d^2} = M_A r_A \omega^2 = M_B r_B \omega^2$$

$$M_A r_A \omega^2 = M_B \left(d - r_A\right)\omega^2 \quad \text{OR} \quad M_A r_A = M_B r_B$$ [M1]

$$\left(M_A + M_B\right) r_A = M_B d$$

$$r_A = \frac{M_B}{M_A + M_B} d$$

$$= \frac{3.00\times10^{31}}{5.00\times10^{31} + 3.00\times10^{31}} 2.50\times10^{12}$$

$$= 9.375\times10^{11} = 9.38\times10^{11} \text{ m}$$ [A1]

(e) **(i)**

$$\rho = \frac{M}{\frac{4}{3}\pi R^3}$$

$$= \frac{5.00\times10^{31}}{\frac{4}{3}\pi\left(1.00\times10^{9}\right)^3}$$

$$= 1.19\times10^{4} \text{ kg m}^{-3}$$ [A1]

(ii) The density of the star increases towards the centre (or with decreasing radius) because the weight of the outer layers compresses the inner layers of the star. [B1] [B1]

8 **(a)** **(i)** Isotopes are nuclei / nuclides which have the same number of protons but different number of neutrons. [B1]

(ii) Nuclear fission is the splitting of a heavy nucleus into two lighter nuclei of approximately the same mass. [B1]

Neutrons are also emitted during nuclear fission. [B1]

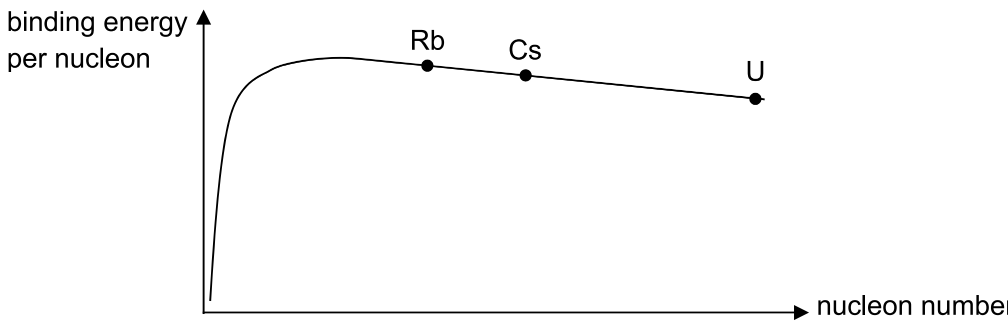
(iii) The half-life of a radioactive nuclide is the time taken for the number of undecayed nuclei to be reduced to half its original number. [B1]

(b) (i) $^{235}_{92}\text{U} + ^{1}_{0}\text{n} \rightarrow ^{137}_{55}\text{Cs} + ^{95}_{37}\text{Rb} + 4^{1}_{0}\text{n}$

p = 1
q = 0
r = 92 – 55 = 37
x = 235 + 1 – 137 – 95 = 4 [B2]

Deduct [1] for each error.

(ii) **1.**



Their relative positions on the curve must be correct. [B1]

2. The products have higher binding energy per nucleon than uranium. (No marks here because awarded in part (ii)1 above.)

The products have a higher **total** binding energy than uranium. [B1]

Hence, the total mass of the products is lighter than that of uranium and this mass difference between reactants and products (or difference in total mass defects between reactants and products) is released as energy when the products are formed. [B1]

(iii) $\Delta m = (235.1727 - 94.92964 - 3 \times 1.008665) \times (1.66 \times 10^{-27}) - m$ [C1]

$\Delta mc^2 = E$

$$\Delta m = \frac{(289 \times 10^6) \times (1.60 \times 10^{-19})}{(3.00 \times 10^8)^2}$$ [M1]

$m = 2.2727 \times 10^{-25}$

$= 2.27 \times 10^{-25}$ kg [A1]

(c) **(i)** Since Caesium is highly soluble, any logical suggestion of removing it from water will be accepted (the contaminated water must be properly disposed of), e.g.by filtration. [B1]

https://www.scientificamerican.com/article/fukushima-water-fallout/:
Unlike drinking water contaminated with microbial pathogens such as Escherichia coli, giardia or cryptosporidium, water containing radioactive material cannot be made potable by boiling, bleach or exposure to ultraviolet light. Instead, isotopes must be removed using activated charcoal filtration, reverse osmosis or water softening, to name a few methods. Radioactive material may also fall out of a water supply by settling to the bottom of a reservoir or via adsorption (adhesion) onto the surface of soil particles in a reservoir.

(ii)

$$\lambda = \frac{\ln 2}{t_{1/2}}$$

$$= \frac{\ln 2}{30.2 \times 365 \times 24 \times 60 \times 60}$$ [M1]

$$= 7.28 \times 10^{-10} \text{ s}^{-1}$$ [A1]

Unit: s^{-1} [B1]

(iii)

$$A_o = \lambda N_o$$

$$= \left(7.28 \times 10^{-10}\right)\left(\frac{27.0}{0.137} \times 6.02 \times 10^{23}\right)$$ [M1]

$$= 8.63 \times 10^{16} \text{ Bq}$$ [A1]

(iv) This is because part of the energy released is carried away as

1. the kinetic energy of the (recoiling) barium-137 due to the conservation of momentum, [B1]
2. the (kinetic and mass) energy of neutrinos, and/or the energy of the gamma radiation produced in the beta-decay. [B1]