SL Paper 2

This question is about radioactivity.

Caesium-137 $\left({}^{137}_{55}\mathrm{Cs}\right)$ is a radioactive waste product with a half-life of 30 years that is formed during the fission of uranium. Caesium-137 decays by the emission of a beta-minus (β^-) particle to form a nuclide of barium (Ba).

a. State the nuclear equation for this reaction. [2]

$$ {}^{137}_{55}\mathrm{Cs} \rightarrow {}^{\cdots\cdots}_{\cdots\cdots}\mathrm{Ba} + {}^{0}_{-1}\beta^{-} + \cdots\cdots $$

b. Determine the fraction of caesium-137 that will have decayed after 120 years. [2]

c. Explain, with reference to the biological effects of ionizing radiation, why it is important that humans should be shielded from the radiation emitted by caesium-137. [2]

Markscheme

a. ${}^{137}_{56}\mathrm{Ba}$;

anti-neutrino / $\bar{v}$;

b. evidence of use of 4 half-lives;

so 0.938 ***or*** 93.8% ***or*** $\frac{15}{16}$ decays;

c. reference to a short-term effect e.g. skin reddening / burning;

reference to a long-term effect e.g. genetic damage / cancer;

reference to relative penetrative power of beta/ionizing power compared to alpha or gamma;

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]

This question is in **two** parts. **Part 1** is about nuclear reactions. **Part 2** is about thermal energy transfer.

Part 1 Nuclear reactions

Part 2 Thermal energy transfer

a. (i) Define the term *unified atomic mass unit.* [2]

(ii) The mass of a nucleus of einsteinium-255 is 255.09 u. Calculate the mass in $MeVc^{-2}$.

c. When particle X collides with a stationary nucleus of calcium-40 (Ca-40), a nucleus of potassium (K-40) and a proton are produced. [6]

$$^{40}_{20}\mathrm{Ca} + \mathrm{X} \rightarrow {}^{40}_{19}\mathrm{K} + {}^{1}_{1}\mathrm{p}$$

The following data are available for the reaction.

Particle	**Rest mass / $MeV\,c^{-2}$**
calcium-40	37 214.694
X	939.565
potassium-40	37 216.560
proton	938.272

(i) Identify particle X.

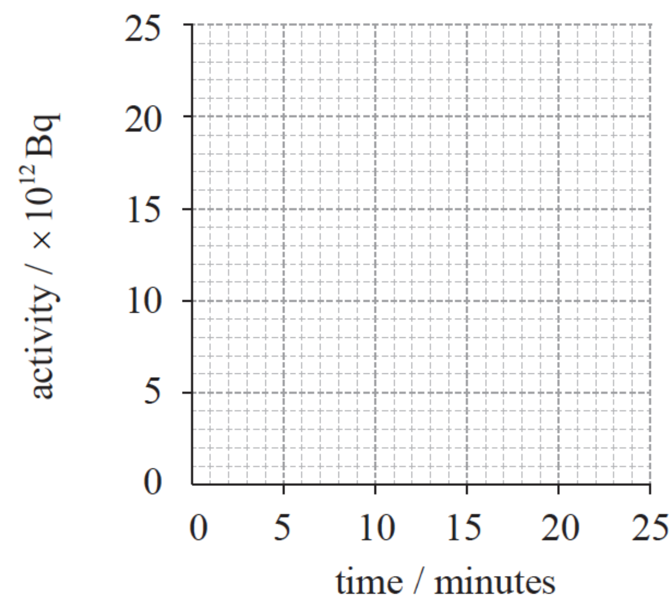
(ii) Suggest why this reaction can only occur if the initial kinetic energy of particle X is greater than a minimum value.

(iii) Before the reaction occurs, particle X has kinetic energy 8.326 MeV. Determine the total combined kinetic energy of the potassium nucleus and the proton.

d. Potassium-38 decays with a half-life of eight minutes. [5]

(i) Define the term *radioactive half-life*.

(ii) A sample of potassium-38 has an initial activity of 24×10^{12}Bq. On the axes below, draw a graph to show the variation with time of the activity of the sample.



(iii) Determine the activity of the sample after 2 hours.

e. (i) Define the *specific latent heat* of fusion of a substance. [5]

(ii) Explain, in terms of the molecular model of matter, the relative magnitudes of the specific latent heat of vaporization of water and the specific latent heat of fusion of water.

f. A piece of ice is placed into a beaker of water and melts completely. [5]

The following data are available.

Initial mass of ice = 0.020 kg
Initial mass of water = 0.25 kg
Initial temperature of ice = 0°C
Initial temperature of water = 80°C
Specific latent heat of fusion of ice = 3.3×10^5 J kg^{-1}
Specific heat capacity of water = 4200 J $kg^{-1}K^{-1}$

(i) Determine the final temperature of the water.

(ii) State **two** assumptions that you made in your answer to part (f)(i).

Markscheme

a. one twelfth of the mass of a carbon-12 atom/ ${}^{12}_{6}\mathrm{C}$;

Do not allow nucleus.

$255.09 \times 931.5 = 237600(\mathrm{MeVc^{-2}})$;
*Award **[1]** for a bald correct answer.*

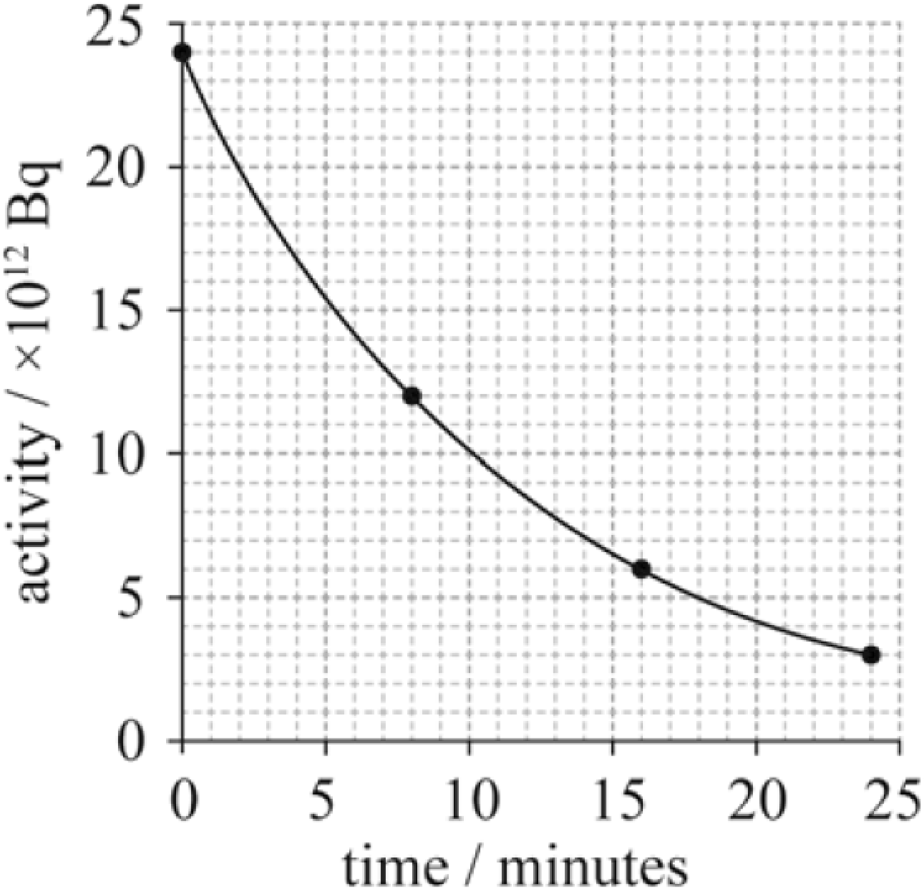
c. (i) neutron/${}^{1}_{0}\mathrm{n}$;

(ii) the (rest) mass of the products is greater than that of the reactants;
energy must be given to supply this extra mass;

(iii) $\Delta m = [37216.560 + 938.272] - [37214.694 + 939.565] = 0.573\ (\mathrm{MeVc^{-2}})$;
energy required for reaction=0.573(MeV);
kinetic energy=(8.326-0.573=)7.753(MeV);
*Award **[3]** for a bald correct answer.*

d. (i) time for the activity of a sample to halve / time for half the radioactive nuclei to decay;

(ii) four data points (0, 24) (8, 12) (16, 6) (24, 3) correct;
smooth curve through points;



(iii) 2 hours (=120 minutes)=15 half-lives;
activity=$\frac{24\times10^{12}}{2^{15}} = 7.3\times10^{8}$ (Bq);

or

$\lambda = \frac{1n2}{8}$; $(A = A_0e^{-\lambda t}\text{method})$;
=7.3×10^{8}(Bq)
*Award **[2]** for a bald correct answer.*

e. (i) the energy (absorbed/released) when a unit mass/one kg;
of liquid freezes (to become solid) at constant temperature / of solid melts (to become liquid) at constant temperature;

(ii) potential energy changes during changes of state / bonds are weakened/broken during changes of state;
potential energy change is greater for vaporization than fusion / more energy is required to break bonds than to weaken them;
SLH vaporization is greater than SLH fusion;
Only award third marking point if first marking point or second marking point is awarded.

f. (i) use of $\Delta Q = mc\Delta T$ and *mL*;
$0.020\times3.3\times10^{5} + 0.020\times4200\times(T-0) = 0.25\times4200\times(80-T)$;
T=68(°C);
*Allow **[3]** for a bald correct answer.*
*Award **[2]** for an answer of T=74°(C) (missed melted ice changing temperature).*

(ii) no energy given off to the surroundings/environment;
no energy absorbed by beaker;
no evaporation of water;

Examiners report

a. i) The definition of the unified atomic mass unit relates to the mass of the carbon 12 atom. Few candidates made this reference.

ii) Almost all were able to convert the mass unit into $MeVc^{-2}$.

c. i) This was well answered with the majority of candidates identifying the neutron.

ii) Few could relate the mass defect to the energy required to initiate the reaction.

iii) Many were able to calculate the mass defect but did not realize that in this reaction it is the energy needed to initiate the reaction. This is why the products have more combined mass than the reactants.

d. i) The definition of radioactive half-life was often poorly done with few appreciating that half the radioactive nuclei decay into a more stable form. Those that explained that the activity of the sample would halve were more successful.

ii) Almost all were able to draw the decay curve.

iii) This was well answered with responses split between those that successfully found the number of half-lives elapsed in 2 hours and going on to find the activity of the sample and those that took the decay constant route. At SL, most successfully found the number of half lives elapsed in 2 hours and were able to find the corresponding activity of the sample.

e. i) The majority related the latent heat to the energy required for a change of state but few successfully completed the definition by explaining that fusion is the change of state between a solid and liquid at constant temperature.

ii) This explanation was poorly done with few gaining full marks. Few could relate the change in potential energy during a change of state to fusion and vaporization.

f. i) Of those candidates that established a relevant energy transfer equation, many did not include the heat gained by the ice once it had melted.

ii) Few could state two sources of energy loss that were not included in their energy equation.