Marks
7

- Technetium-99m is an important radionuclide for medical imaging. It is produced from molybdenum-99. Fill in the box below to give a balanced nuclear equation for the production of Tc-99m from Mo-99.

$$^{99}_{42}\text{Mo} \rightarrow\ ^{99m}_{43}\text{Tc} + \boxed{^{0}_{-1}\text{e}}$$

The half-life of Tc-99m is 6.0 hours. Calculate the decay constant, λ, in s^{-1}.

The half life, $t_{1/2}$, is equal to:

$$t_{1/2} = \ln 2 / \lambda = \ln 2 / (6.0 \times 60. \times 60.\ s) = 3.2 \times 10^{-5}\ s^{-1}$$

Answer: **$3.2 \times 10^{-5}\ s^{-1}$**

Calculate the molar activity in Bq mol^{-1}.

A mol of Tc-99m contains 6.022×10^{23} nuclei. As activity $A = \lambda N$ where N is the number of nuclei:

$$A = (3.2 \times 10^{-5}\ s^{-1}) \times (6.022 \times 10^{23}\ \text{nuclei mol}^{-1}) = 1.9 \times 10^{19}\ \text{Bq mol}^{-1}$$

Answer: **1.9×10^{19} Bq mol^{-1}**

Calculate the time in hours for 90% of the activity of a sample of Tc-99m to decay.

The number of nuclei changes with time according to $\ln(N_0/N_t) = \lambda t$. If 90% of the nuclei have decayed, $N_t = 0.10 \times N_0$ or $N_0 / N_t = 1 / 0.10$. Hence:

$$\ln(N_0/N_t) = \lambda t$$

$$\ln(1 / 0.10) = (3.2 \times 10^{-5}\ s^{-1}) \times t$$

$$t = 72000\ s = 20\ \text{hours}$$

Answer: **20 hours**

Why is Tc-99m suitable for medical imaging? Give two reasons.

Appropriately short half-life allows time for production of nuclide, administration to patient, and for it to accumulate in the tissue of interest. Activity is high enough to give good quality image with small amount of nuclide.

It is a gamma emitter – highly penetrating radiation that can be detected outside the body and is not damaging to human tissue as it is non-ionising.

Its chemical properties allow it to be incorporated into molecules that will be absorbed by the organs to be investigated.

Marks 6

- The isotope $^{60}_{27}Co$ undergoes radioactive decay to produce a stable isotope of nickel. Give the balanced equation for this decay process.

$$^{60}_{27}\mathbf{Co} \rightarrow\ ^{60}_{28}\mathbf{Ni} +\ ^{0}_{-1}e$$

The half-life of ^{60}Co is 5 years. Calculate the value of the decay constant, λ, (in s^{-1}).

The decay constant, λ, is given by:

$$\lambda = \ln 2 / t_{1/2} = \ln 2 / (5 \times 365.25 \times 24 \times 60 \times 60 \text{ s}) = 4 \times 10^{-9} \text{ s}^{-1}$$

Answer: **4×10^{-9} s^{-1}**

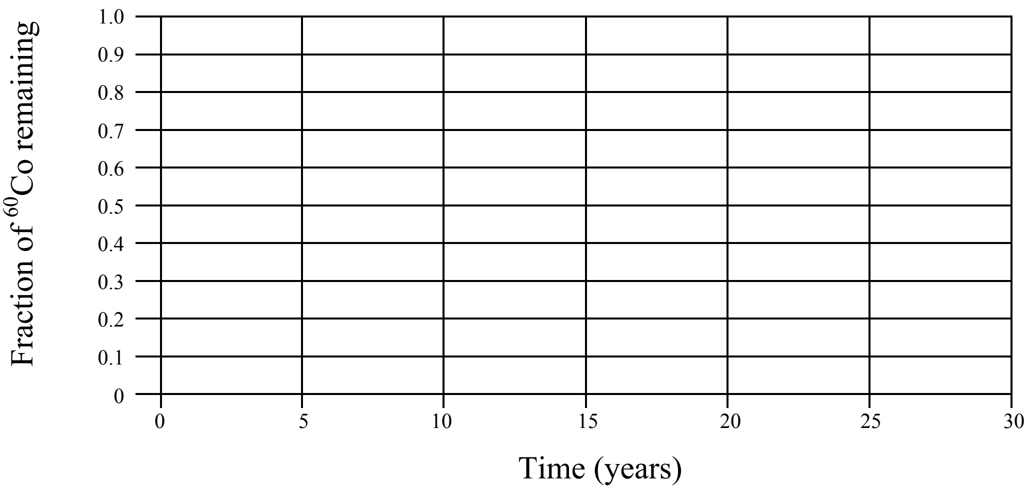
What is the molar activity of ^{60}Co (in Bq mol^{-1})?

The molar activity, *A*, is given by $A = \lambda N_A$ where N_A is Avogadro's number. Hence:

$$A = (4 \times 10^{-9} \text{ s}^{-1}) \times (6.022 \times 10^{23} \text{ particles mol}^{-1})$$
$$= 3 \times 10^{15} \text{ particles s}^{-1} \text{ mol}^{-1} = 3 \times 10^{15} \text{ Bq mol}^{-1}$$

Answer: **3×10^{15} Bq mol^{-1}**

Complete the graph below.



Estimate from the graph the fraction of ^{60}Co remaining after 12 years.

Marks 4

- Radioactivity may have damaging effects on humans but can also be used for medical imaging to potentially save lives. Which of alpha and gamma radiation is better suited for medical imaging? Give reasons.

Gamma radiation is more useful as it is more penetrating (so can be detected by detector placed outside the body) and is less damaging to human tissue than alpha radiation. As alpha radiation is charged, it leads ionisation and causes more damage and is less penetrating.

Given nuclides with half-lives of minutes, hours or years, which would be best used for medical imaging? Explain.

Nuclides with half-lives of hours are best suited. This allows time for production of nuclide, administration to patient, and for it to accumulate in the tissue of interest. Activity is high enough to give good quality image with small amount of nuclide. A long half-life means a lower activity and hence more nuclide needs to be used to generate a quality image.

Marks
2

- Complete the blanks in the following nuclear equations.

$^{54}_{27}\text{Co} \rightarrow {}^{54}_{26}\text{Fe} + {}^{0}_{1}e$ **or** ${}^{0}_{1}\beta$ **or** $\boldsymbol{\beta^{+}}$
$^{238}_{92}\text{U} \rightarrow {}^{234}_{90}\text{Th} + \alpha$

Marks 5

- The generation of energy in a nuclear reactor is largely based on the fission of either ^{235}U or ^{239}Pu. The fission products include every element from zinc through to the *f*-block. Explain why most of the radioactive fission products are β-emitters.

The optimal n:p ration increases as *Z* increases. Splitting a large nucleus in two will almost certainly produce nuclides with similar n:p ratios to the parent, which will now be too high. They will emit negative charge to convert neutrons to protons, bringing about a more satisfactory n:p ratio. *i.e.* they will be β emitters.

The radioactivity of spent fuel rods can be modelled by the exponential decay of ^{137}Cs, which has a half-life of 30.23 years. What is the specific activity of ^{137}Cs, in Bq g^{-1}?

The number of nuclei, *N*, in 1.00 g of ^{137}Cs is:

number of nuclei = number of moles × Avogadro's constant

$$N = \left(\frac{1.00}{137}\text{ mol}\right) \times (6.022 \times 10^{23}\text{ nuclei mol}^{-1}) = 4.40 \times 10^{21}\text{ nuclei}$$

The activity (*A*) is related to *N* by $A = \lambda N$ where λ is the decay constant. The half life, $t_{½}$, is related to the decay constant, λ, by $t_{½} = \ln 2/\lambda$. Hence,

$$\lambda = \ln 2/(30.23 \times 365 \times 24 \times 60 \times 60\text{ s}) = 7.271 \times 10^{-10}\text{ s}^{-1}$$

The activity is thus,

$$A = \lambda N = (7.271 \times 10^{-10}\text{ s}^{-1}) \times (4.40 \times 10^{21}\text{ nuclei})$$

$$= 3.19 \times 10^{12}\text{ nuclei s}^{-1} = 3.19 \times 10^{12}\text{ Bq}$$

Answer: **3.19×10^{12} Bq g^{-1}**

Marks 6

- On the 6th of April 2011, after the earthquake and tsunami in Japan, levels of ^{131}I in seawater were recorded at 7.5×10^6 times the legal limit. The half-life of ^{131}I is 8.02 days. How long will it take for the radioactivity of the initially sampled seawater to fall back to the legal limit?

The radioactivity is proportional to the number of radioactive nuclei, $A = \lambda N$. As the number of radioactive nuclei varies with time according to $\ln(N_0/N_t) = \lambda t$:

$$\ln(A_0/A_t) = \lambda t$$

Using $t_{1/2} = \ln 2 / \lambda$:

$$\lambda = \ln 2 / t_{1/2} = \ln 2 / 8.02 \text{ days}^{-1} = 0.0864 \text{ days}^{-1}$$

if $A_0 = 7.5 \times 10^6 \times A_t$,

$$\ln(7.5 \times 10^6) = (0.0864 \text{ days}^{-1}) \times t$$

$$t = 183 \text{ days}$$

Answer: **183 days**

Why is the ^{131}I nucleus unstable?

The $^{131}_{53}I$ nucleus lies outside the zone of stability - its neutron to proton ratio is too high.

Write a balanced equation for a likely decay mechanism of ^{131}I.

$$^{131}_{53}I \rightarrow {}^{131}_{54}Xe + {}^{0}_{-1}\beta$$

Another significant seawater contaminant detected after the tsunami was ^{137}Cs, which has a half-life of 30 years. If you were exposed to equal concentrations of both isotopes for 1 hour, which isotope, ^{137}Cs or ^{131}I, would do more damage? Explain your reasoning.

^{131}I would do more damage.

It has the shorter half-life so undergoes more disintegrations and produces more radiation in a given time period.

Marks 5

- How does the ratio of the number of neutrons to the number of protons in a stable or long-lived radionuclide change as the atomic number increases?

The proton to neutron ratio slowly increases from 1 (for deuterium) to ~1.5 for bismuth.

For light elements, the ratio is approximately 1. As the number of protons grows, increasing numbers of neutrons are needed to stabilise the nucleus.

After ^{208}Pb, all nuclei are unstable.

The generation of energy in a nuclear reactor is largely based on the fission of certain long-lived radionuclides (usually ^{235}U or ^{239}Pu). The fission products include every element from zinc through to the *f*-block. Explain why most of the radioactive fission products are β-emitters.

The optimal ratio between the number of neutrons, *n*, and the number of protons, *p*, increases as *Z* increases.

Simply splitting a large nucleus in two will produce nuclides with similar *n*:*p* ratios to the parent, which will now be too high. They will emit negative charge to convert neutrons to protons, bringing about a more satisfactory *n*:*p* ratio. *i.e.* they will be β emitters.

Two of the more common isotopes produced in nuclear reactors are ^{131}I (half-life of 8.02 days) and ^{137}Cs (half-life of 30 years). Both are β-emitters. If you were exposed to equal concentrations of both isotopes for 1 hour, which isotope, ^{137}Cs or ^{131}I, would do more damage? Explain your reasoning.

^{131}I would do more damage.

It has the shorter half-life so undergoes more disintegrations and produces more radiation in a given time period.

- Radon gas decays into polonium with a half-life of 3.82 days via the following mechanism: 3

$$^{222}_{86}\text{Rn} \rightarrow {}^{218}_{84}\text{Po} + {}^{4}_{2}\text{He}$$

Give three reasons why $^{222}_{86}\text{Rn}$ is biologically a very harmful nuclide.

The half-life is relatively short and therefore it is highly radioactive.

The radioactive element is a gas and can therefore easily be inhaled into the lungs.

It produces alpha particles which are ionizing. They are stopped by tissue and do not escape the body: they do internal damage, especially to the lungs.

Marks
3

- Consider the process of electron capture by the manganese-54 isotope.

  Write a balanced nuclear formula.

In electron capture, a proton in the nucleus captures a core electron and is converted into a neutron. The atomic mass does not change but the atomic number decreases by 1:

$$\mathbf{{}^{54}_{25}Mn + {}^{0}_{-1}e \rightarrow {}^{54}_{24}Cr}$$

Marks 8

- Sixteen unstable isotopes of strontium are known to exist. Of greatest importance are ^{90}Sr with a half-life of 28.78 years and ^{89}Sr with a half-life of 50.5 days. ^{90}Sr is found in nuclear fallout as it is a by-product of nuclear fission.

  Calculate the activity (in Bq) of 20.0 g of ^{90}Sr.

As 1 mol of ^{90}Sr has a mass of 90.0 g, the number of nuclei, N, in 20.0g is:

number of nuclei = number of moles × Avogadro's constant

$$N = \left(\frac{20.000}{90.0}\ \text{mol}\right) \times (6.022 \times 10^{23}\ \text{nuclei mol}^{-1}) = 1.34 \times 10^{23}\ \text{nuclei}$$

The activity (A) is related to N by $A = \lambda N$ where λ is the decay constant. The half life, $t_{½}$, is related to the decay constant, λ, by $t_{½} = \ln2/\lambda$. Hence,

$$\lambda = \ln2/(28.78 \times 365 \times 24 \times 60 \times 60\ \text{s}) = 7.64 \times 10^{-10}\ \text{s}^{-1}$$

The activity is thus,

$$A = \lambda N = (7.64 \times 10^{-10}\ \text{s}^{-1}) \times (1.34 \times 10^{23}\ \text{nuclei})$$

$$= 1.02 \times 10^{14}\ \text{nuclei s}^{-1} = 1.02 \times 10^{14}\ \text{Bq}$$

Answer: **1.02×10^{14} Bq**

Calculate the age (to the nearest year) of a sample of ^{90}Sr that has an activity one-eighth of a freshly prepared sample.

The number of radioactive nuclei changes with time according to the equation:

$$\ln(N_0/N_t) = \lambda t$$

As the activity is proportional to the number of nuclei, this can also be written in terms of activities:

$$\ln(A_0/A_t) = \lambda t$$

If the activity has decreased to one eighth of its original value, $A_0/A_t = 8$. Hence:

$$\ln(8) = (7.64 \times 10^{-10}\ \text{s}^{-1}) \times t$$

$$t = 2.72 \times 10^{9}\ \text{s} = (2.72 \times 10^{9} / (365 \times 24 \times 60 \times 60)\ \text{years} = 86.3\ \text{years}$$

Answer: **86 years**

ANSWER CONTINUES ON THE NEXT PAGE

Determine the specific activity of ^{90}Sr in Ci g^{-1}.

From above, the activity of 20.0 g of ^{90}Sr is 1.02×10^{14} Bq so the activity of one gram is (1.02×10^{14} Bq)/ (20 g) = 5.11×10^{12} Bq g^{-1}.

As 1 Ci = 3.70×10^{10} Bq, this corresponds to:

specific activity = (5.11×10^{12}) / (3.70×10^{10}) Ci g^{-1} = 138 Ci g^{-1}

Answer: **138 Ci g^{-1}**

^{90}Sr presents a long-term health problem as it substitutes for calcium in bones. Comment on why Sr can substitute for Ca so readily.

Sr has similar electronic structure to Ca - both have s^2 valence shell configuration.

The Sr^{2+} and Ca^{2+} cations have the same charge and are of similar size.

Marks

- Scholars think that a parchment scroll recently found in the Middle East could have originated from the same group responsible for the Dead Sea Scrolls. If a modern piece of parchment has an activity of 4.0×10^{-4} Ci g^{-1}, calculate the expected activity of the recently discovered scroll if it originated 2100 years ago. **2**

The ^{14}C age of a sample is given by:

$$^{14}\text{C age} = 8033 \ln\left(\frac{A_0}{A_t}\right) \text{ years}$$

If the ^{14}C age is 2100 years and its initial activity, $A_0 = 4.0 \times 10^{-4}$ Ci g^{-1},

$$2100 \text{ years} = 8033 \ln\left(\frac{4.0 \times 10^{-4} \text{ Ci g}^{-1}}{A_t}\right)$$

$$A_t = 3.1 \times 10^{-4} \text{ Ci g}^{-1}$$

Answer: $A_t = 3.1 \times 10^{-4}$ **Ci g^{-1}**

- ^{11}C is an unstable isotope of carbon. Which force within the ^{11}C nucleus is responsible for its instability? Explain. **2**

^{11}C has 6 protons but only 5 neutrons. Stable nuclei for the lighter elements have approximately equal numbers of neutrons and protons. ^{11}C has too many protons relative to neutrons within the nucleus.

Electrostatic repulsion between protons destabilises the nucleus.

Which force is responsible for the greater stability of the ^{12}C isotope compared to the ^{11}C isotope? Explain.

^{12}C has 6 protons and 6 neutrons. The one extra neutron compared to ^{11}C increases the strength of the *strong nuclear force* between all nucleons (protons and neutrons). This overcomes the electrostatic repulsion of the protons and results in a stable nucleus.

- Write two possible mechanisms for the radioactive decay of ^{83}Rb to ^{83}Kr.

Marks 5

$^{83}_{37}\text{Rb} \rightarrow ^{83}_{36}\text{Kr} + ^{0}_{+1}e$ **(positron decay)**

$^{83}_{37}\text{Rb} + ^{0}_{-1}e \rightarrow ^{83}_{36}\text{Kr}$ **(electron capture decay)**

The half-life of ^{83}Rb is 86.2 days. Calculate the activity (in Bq) of an isotopically pure 1.000 g sample of ^{83}Rb. (The molar mass of ^{83}Rb is 82.915110 g mol^{-1}.)

As 1 mol of ^{83}Rb has a mass of 82.915110 g, the number of nuclei, *N*, in 1.000 g is:

number of nuclei = number of moles × Avogadro's constant

$$N = \left(\frac{1.000}{82.915110}\text{ mol}\right) \times (6.022 \times 10^{23}\text{ nuclei mol}^{-1}) = 7.263 \times 10^{21}\text{ nuclei}$$

The activity (A) is related to N by $A = \lambda N$ where λ is the decay constant. The half life, $t_{½}$, is related to the decay constant, λ, by $t_{½} = \ln 2/\lambda$. Hence,

$$\lambda = \ln 2/(86.2 \times 24 \times 60 \times 60\text{ s}) = 9.31 \times 10^{-8}\text{ s}^{-1}$$

The activity is thus,

$$A = \lambda N = (9.31 \times 10^{-8}\text{ s}^{-1}) \times (7.263 \times 10^{21}\text{ nuclei})$$
$$= 6.76 \times 10^{14}\text{ nuclei s}^{-1} = 6.76 \times 10^{14}\text{ Bq}$$

Answer: **6.76×10^{14} Bq**

How many days will it take for this sample to diminish to 1 % of its initial activity?

The number of radioactive nuclei decays with time according to $\ln(N_0/N_t) = \lambda t$. As the activity is proportional to the number of nuclei ($A = \lambda N$), this can be rewritten as:

$$\ln(A_0/A_t) = \lambda t$$

If the activity drops to 1% of its initial value, $A_0/A_t = (100/1) = 100$.
As $\lambda = 9.31 \times 10^{-8}$ s^{-1}:

$$\ln(100) = (9.31 \times 10^{-8}\text{ s}^{-1})t$$

$$t = 49000000\text{ s} = 600\text{ days}$$

Answer: **600 days**

Marks 5

- Write two possible mechanisms for the radioactive decay of ^{55}Fe to ^{55}Mn.

Electron capture: $^{55}_{26}\text{Fe} + {}^{0}_{-1}\text{e} \rightarrow {}^{55}_{25}\text{Mn}$

Positron emission: $^{55}_{26}\text{Fe} \rightarrow {}^{55}_{25}\text{Mn} + {}^{0}_{+1}\text{e}$

The activity of an isotopically pure 1.000 g sample of ^{55}Fe is measured as 8.750×10^{13} Bq. Calculate the half-life (in days) of ^{55}Fe.
(The molar mass of ^{55}Fe is 54.94 g mol^{-1}.)

As the atomic mass of isotopically pure ^{55}Fe is 54.94 g mol^{-1}, the number of moles in 1.000 g is:

$$\text{number of moles} = \frac{\text{mass (g)}}{\text{atomic mass (g mol}^{-1}\text{)}} = \frac{1.000\text{ g}}{54.94\text{ g mol}^{-1}} = 0.01820\text{ g mol}^{-1}$$

This corresponds to:

$$\text{number of nuclei} = \text{number of moles} \times \text{Avogadro's number}$$
$$= (0.01820\text{ mol}) \times (6.022 \times 10^{23}\text{ mol}^{-1}) = 1.096 \times 10^{22}\text{ nuclei}$$

The activity (A) is related to the number of nuclei (N) by $A = \lambda N$ where λ is the decay constant. Hence,

$$\lambda = \frac{A}{N} = \frac{8.750\times10^{13}\text{ Bq}}{1.096\times10^{22}\text{ nuclei}} = 7.983 \times 10^{-9}\text{ s}^{-1}$$

The half life, $t_{½}$, is related to the decay constant by $t_{½} = \ln2/\lambda$. Hence,

$$t_{½} = \ln2/(7.983 \times 10^{-9}) = 8.683 \times 10^{7}\text{ s}$$

As 1 day is (24 × 60 × 60) s, this corresponds to

$$t_{½} = \frac{8.683 \times 10^{7}\text{ s}}{(24\times60\times60)\text{ s day}^{-1}} = 1005\text{ days}$$

Answer: **1005 days**

ANSWER CONTINUES ON THE NEXT PAGE

How many years will it take for the activity of this pure 1.000 g sample of ^{55}Fe to drop to 1.000×10^{9} Bq?

The number of radioactive nuclei decays with time according to $\ln(N_0/N_t) = \lambda t$. As the activity is proportional to the number of nuclei ($A = \lambda N$), this can be rewritten as:

$$\ln(A_0/A_t) = \lambda t$$

As $\lambda = 7.983 \times 10^{-9}\ s^{-1}$, the activity will decay from $A_0 = 8.750 \times 10^{13}$ Bq to $A_t = 1.000 \times 10^{9}$ Bq in a time t where

$$\ln(8.750 \times 10^{13}/1.000 \times 10^{9}) = (7.983 \times 10^{-9}\ s^{-1})t$$

$$t = 1.425 \times 10^{9}\ s$$

As 1 year is (365 × 24 × 60 × 60) s, this corresponds to:

$$t = 1.425 \times 10^{9} / (365 \times 24 \times 60 \times 60) = 45.19 \text{ years}$$

Answer: **45.19 years**

Marks 6

- Write down an equation representing the decay mechanism of ^{14}C.

$^{14}_{6}C \rightarrow ^{14}_{7}N + ^{0}_{-1}\beta$

The half-life of ^{14}C is 5730 years. What is the activity of precisely 1 g of this isotope, given that each atom weighs 14.00 amu? Give your answer in Bq.

As 1 mol of ^{14}C has a mass of 14.00 g, the number of nuclei, N, in 1 g is:

number of nuclei = number of moles × Avogadro's constant

$N = (\frac{1.000}{14.00}\text{ mol}) \times (6.022 \times 10^{23}\text{ nuclei mol}^{-1}) = 4.301 \times 10^{22}\text{ nuclei}$

The activity (A) is related to N by $A = \lambda N$ where λ is the decay constant. The half life, $t_{½}$, is related to the decay constant, λ, by $t_{½} = \ln2/\lambda$. Hence,

$\lambda = \ln2/(5730 \times 365 \times 24 \times 60 \times 60\text{ s}) = 3.84 \times 10^{-12}\text{ s}^{-1}$

The activity is thus,

$A = \lambda N = (3.84 \times 10^{-12}\text{ s}^{-1}) \times (4.301 \times 10^{22}\text{ nuclei})$

$= 1.65 \times 10^{11}\text{ nuclei s}^{-1} = 1.65 \times 10^{11}\text{ Bq}$

Answer: **1.65×10^{11} Bq**

Carbon-14 is used as a radioactive tracer in the urea breath test, a diagnostic test for *Helicobacter pylori*. Name an instrument which can be used to detect radioactive carbon dioxide in the breath of a patient.

A scintillation counter

A patient ingests 1.00 g of urea with a total activity of 1.00 μCi. What is the percentage, by weight, of carbon-14 in this sample?

As 1 Ci = 3.70×10^{10} Bq, from above, the activity per gram of ^{14}C is,

$A = \frac{1.65 \times 10^{11}}{3.70 \times 10^{10}}\text{ Ci} = 4.46\text{ Ci}$

As the actual activity of urea is 1.00 μCi or 1.00×10^{-6} Ci, the percentage by weight that must be ^{14}C is,

$\text{percentage } ^{14}C = \frac{1.00 \times 10^{-6}}{4.46} \times 100\ \% = 2.2 \times 10^{-5}\ \%$

Answer: **2.2×10^{-5} %**

Marks

- Balance the following nuclear reactions by identifying the missing nuclear particle or nuclide. **3**

$$^{55}_{26}Fe + ^{0}_{-1}e \rightarrow \boxed{\mathbf{^{55}_{25}Mn}}$$

$$^{3}_{2}He + ^{3}_{2}He \rightarrow 2\,^{1}_{1}p + \boxed{\mathbf{^{4}_{2}He}}$$

$$^{15}_{7}N + ^{1}_{1}p \rightarrow ^{15}_{8}O + \boxed{\mathbf{^{1}_{0}n}}$$

- Calculate the atomic mass of lead from the isotope information provided. **2**

Isotope	Mass of isotope (a.m.u.)	Relative abundance
^{204}Pb	203.97304	1.40%
^{206}Pb	205.97446	24.10%
^{207}Pb	206.97589	22.10%
^{208}Pb	207.97664	52.40%

The relative atomic mass of lead is the weighted average of the masses of its isotopes:

$$\text{atomic mass} = \left(203.97304 \times \frac{1.40}{100}\right) + \left(205.97446 \times \frac{24.10}{100}\right) + \left(206.97589 \times \frac{22.10}{100}\right) + \left(207.97664 \times \frac{52.40}{100}\right) = 207.2$$

(The relative abundances are given to 4 significant figures and limit the accuracy of the answer.)

Answer: **207.2**

- Calculate the molar activity of ^{11}C (in curie), given its half-life of 20.3 minutes. **3**

The molar activity is given by $A_{mol} = \lambda N_a$ where λ is the decay constant which is related to the half life $t_{1/2}$ by $\lambda = \frac{\ln 2}{t_{1/2}}$.

The half life = 20.3 minutes or 20.3 × 60 s = 1218 s. Hence the molar activity is:

$$A_{mol} = \left(\frac{\ln 2}{1218}\right) \times (6.022 \times 10^{23}) = 3.427 \times 10^{20}\,\text{Bq} = \frac{3.427 \times 10^{20}}{3.70 \times 10^{10}}\,\text{Ci} = 9.26 \times 10^{9}\,\text{Ci}$$

Answer: **9.26×10^{9} Ci**

Marks

- Balance the following nuclear reactions by identifying the missing nuclear particle or nuclide. **3**

$${}^{60}_{29}\text{Cu} \rightarrow \boxed{\mathbf{{}^{60}_{28}Ni}} + {}^{0}_{+1}\text{e}$$

$$\boxed{\mathbf{{}^{55}_{26}Fe}} + {}^{0}_{-1}\text{e} \rightarrow {}^{55}_{25}\text{Mn}$$

$${}^{28}_{14}\text{Si} + {}^{2}_{1}\text{H} \rightarrow {}^{29}_{15}\text{P} + \boxed{\mathbf{{}^{1}_{0}\boldsymbol{n}}}$$

- Calculate the following properties of the ^{13}N nuclide, given that its half-life is 9.96 minutes. **3**

(a) the decay constant in s^{-1}

9.96 minutes corresponds to (9.96 × 60.0) = 598 s.

The half life is related to the decay constant, *λ*, by $\lambda = \frac{\ln 2}{t_{1/2}} = \frac{\ln 2}{598} = 1.16 \times 10^{-3}\ s^{-1}$

Answer: λ = **1.16 × 10^{-3} s^{-1}**

(b) the molar activity in Ci mol^{-1}

The activity, *A*, is related to *λ* by *A* = *λN* where *N* is the number of nuclei. The activity of a mole is thus:

$$A = \lambda N = (1.16 \times 10^{-3}) \times (6.022 \times 10^{23}) = 6.98 \times 10^{20}\ \text{Bq mol}^{-1}$$

As 1 Bq = 3.70 × 10^{10} Bq, this corresponds to:

$$A = 6.98 \times 10^{20}\ \text{Bq mol}^{-1} = \frac{6.98 \times 10^{20}}{3.70 \times 10^{10}}\ \text{Ci mol}^{-1} = 1.89 \times 10^{10}\ \text{Ci mol}^{-1}$$

Answer: **1.89 × 10^{10} Ci mol^{-1}**

Marks

- Balance the following nuclear reactions by identifying the missing nuclear particle or nuclide. **3**

$${}^{63}_{28}\text{Ni} \rightarrow {}^{63}_{29}\text{Cu} + \boxed{\mathbf{{}^{0}_{-1}\beta}}$$

$${}^{53}_{26}\text{Fe} + {}^{0}_{-1}\text{e} \rightarrow \boxed{\mathbf{{}^{53}_{25}Mn}}$$

$${}^{28}_{14}\text{Si} + {}^{2}_{1}\text{H} \rightarrow {}^{1}_{0}\text{n} + \boxed{\mathbf{{}^{29}_{15}P}}$$

- Calculate the energy (in J) and the wavelength (in nm) of the photon of radiation emitted when the electron in Be^{3+} drops from an n = 3 state to an n = 2 state. **3**

As Be^{3+} has one electron, the equation $E_n = \frac{-E_R Z^2}{n^2}$ where $E_R = 2.18\times10^{-18}$ J can be used. Beryllium has Z = 4. The energies of the n = 3 and n =2 levels are:

$$E_2 = \frac{-E_R(4)^2}{(2)^2} = -4E_R \text{ and } E_3 = \frac{-E_R(4)^2}{(3)^2} = -\frac{16}{9}E_R = 1.78E_R$$

The separation is (4 - 1.78)E_R = 2.22E_R = 2.22 × (2.18 × 10^{-18}) = 4.84 × 10^{-18} J.

$$\text{As } E = \frac{hc}{\lambda},\ \lambda = \frac{hc}{E} = \frac{(6.626\times10^{-34})\times(2.998\times10^{8})}{(4.84\times10^{-18})} = 4.10\times10^{-8}\text{ m} = 41.0\text{ nm}$$

Energy: **4.84 × 10^{-18} J**	Wavelength: **4.10 ×10^{-8} m or 41.0 nm**

	Marks
• Balance the following nuclear reactions by identifying the missing nuclear particle or nuclide.	4

$$^{212}_{83}\text{Bi} \rightarrow {}^{208}_{81}\text{Tl} + \boxed{\mathbf{^{4}_{2}He}}$$

$$^{8}_{4}\text{Be} + \boxed{\mathbf{^{4}_{2}He}} \rightarrow {}^{12}_{6}\text{C}$$

$$^{14}_{7}\text{N} + {}^{1}_{0}\text{n} \rightarrow {}^{1}_{1}\text{p} + \boxed{\mathbf{^{14}_{6}C}}$$

What is a common source of the neutrons in the previous reaction?

Stars

• Explain why solid α emitters are generally considered as low risk radioisotopes while gaseous α emitters are high risk. **2**

α-Radiation is highly ionising and causes severe tissue damage, but it is not very penetrating and easily stopped by our skin. Gaseous α-emitters are high risk as they can be breathed in and lodge in the lungs and then be transported round the body. Solid α-emitters are not dangerous unless ingested, which only happens in rare circumstances.

Marks

- Balance the following nuclear reactions by identifying the missing nuclear particle or nuclide. **3**

$$^{55}_{26}\text{Fe} + ^{0}_{-1}\text{e} \rightarrow \boxed{\mathbf{^{55}_{25}Mn}}$$

$$^{2}_{1}\text{H} + ^{1}_{1}\text{H} \rightarrow ^{3}_{2}\text{He} + \boxed{\boldsymbol{\gamma}}$$

$$^{15}_{7}\text{N} + ^{1}_{1}\text{p} \rightarrow ^{15}_{8}\text{O} + \boxed{\mathbf{^{1}_{0}n}}$$

- Calculate the atomic mass of silicon from the isotope information provided. **2**

Isotope	Mass of isotope (a.m.u.)	Relative abundance
^{28}Si	27.97693	92.21%
^{29}Si	28.97649	4.70%
^{30}Si	29.97376	3.09%

The relative atomic mass of silicon is the weighted average of the masses of its isotopes:

$$\left(27.97693\times\frac{92.21}{100}\right)+\left(28.97649\times\frac{4.70}{100}\right)+\left(29.97376\times\frac{3.09}{100}\right)=28.09\,\text{g mol}^{-1}$$

Answer: **28.09 g mol^{-1}**

- Calculate the molar activity of ^{3}H (in Curie), given its half-life of 12.26 years. **3**

The molar activity is given by $A_{mol} = \lambda N_a$ where λ is the decay constant which is related to the half life $t_{1/2}$ by $\lambda = \frac{\ln 2}{t_{1/2}}$.

The half life = 12.26 years or 12.26 × 365 × 24 × 3600 s = 3.866 × 10^{8} s. Hence the molar activity is:

$$A_{mol} = \frac{\ln(2)}{3.87\times 10^{8}\text{ s}} \times (6.022 \times 10^{23}\text{ disintegrations mol}^{-1})$$

$$= 1.080 \times 10^{15}\text{ disintegtration s}^{-1}\text{ mol}^{-1}$$

As 1 Ci = 3.70 × 10^{10} disintegrations s^{-1}, the molar activity in Curie is:
1.080 × 10^{18} / 3.70 × 10^{10} = 2.92 × 10^{4} Ci mol^{-1}.

Answer: **2.92 × 10^{4} Ci mol^{-1}**

Marks 4

- Balance the following nuclear reactions by identifying the missing nuclear particle or nuclide.

$$^{1}_{1}H + ^{1}_{1}H \rightarrow ^{2}_{1}H + \boxed{^{0}_{1}\beta}$$

$$^{2}_{1}H + \boxed{^{1}_{1}p} \rightarrow ^{3}_{2}He$$

$$^{3}_{2}He + ^{3}_{2}He \rightarrow \boxed{^{4}_{2}He} + ^{1}_{1}H + ^{1}_{1}H$$

Where might these reactions occur naturally?

In stars

3

- The half life of ^{131}I is 8.06 days. Calculate the activity, in Bq, of 12.0 g of pure ^{131}I. Calculate the activity of ^{131}I in Ci mol^{-1}.

The molar activity is given by $A_{mol} = \lambda N_a$ where λ is the decay constant which is related to the half life $t_{1/2}$ by $\lambda = \frac{\ln 2}{t_{1/2}}$. The half life = 8.06 days or 8.06 × 24 × 3600 s = 696384 s. Hence the molar activity is:

$$A_{mol} = \left(\frac{\ln 2}{696384}\right) \times (6.02 \times 10^{23}) = 5.99 \times 10^{17} \text{ disintegrations s}^{-1} \text{ mol}^{-1}$$

12.0 g of ^{131}I corresponds to 12.0 / 131 = 0.092 mol. The activity of this amount of ^{131}I is therefore 0.092 × (5.99 × 10^{17}) = 5.49 × 10^{16} Bq

As 1 Ci = 3.70 × 10^{10} disintegrations s^{-1}, the molar activity in Curie is:

$$\text{molar activity} = \frac{5.99 \times 10^{17}}{3.70 \times 10^{10}} = 1.62 \times 10^{7} \text{ Ci mol}^{-1}.$$

Answer: **5.49 × 10^{16}** Bq	Answer: **1.62 × 10^{7}** Ci mol^{-1}