- Give the oxidation number of the indicated atom in the following compounds. **2**

Compound	Atom	Oxidation number
HNO_2	N	**+III or +3**
NI_3	N	**-III or -3**
$[Co(NH_3)_5Cl]SO_4$	Co	**+III or +3**
$K_3[CrCl_6]$	Cr	**+III or +3**

Marks
6

- Balance the following nuclear reactions and name the decay process occurring.

Equation	Name of decay process
${}^{15}_{8}O \rightarrow {}^{15}_{7}N + \boxed{{}^{0}_{1}e}$	**positron emission**
${}^{238}_{92}U \rightarrow {}^{234}_{90}Th + \boxed{{}^{4}_{2}He}$	**α decay**
${}^{40}_{19}K + \boxed{{}^{0}_{-1}e} \rightarrow {}^{40}_{18}Ar$	**electron capture**

Marks

- What mass of isotope would be initially required if a medical procedure needs 2.0 mg of ^{99m}Tc exactly 50. hours later? The half life of ^{99m}Tc is 6.0 hours. **2**

The activity coefficient, λ, is related to the half life, $t_{1/2}$ through:

$$\lambda = \ln 2 / t_{1/2} = \ln 2 / (6.0 \text{ hours}) = 0.115 \text{ hours}^{-1}$$

The number of nuclei, *N*, decays with time according to:

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

As the mass is proportional to the number of nuclei, this can be rewritten as:

$$\ln(m_0 / m_t) = \lambda t$$

If the mass after t = 50. hours is m_t = 2.0 mg, then

$$\ln(m_0 / 2.0) = (0.115) \times (50)$$

so:

$$m_0 = 650 \text{ mg}$$

Answer: **650 mg**

- Comment on the stability of the following nuclides, and the type of radioactive decay (if any) that they undergo. **3**

$^{18}_{10}$Ne

For this nuclide, Z = 10 and N = (18 – 10) = 8. With an N:Z ratio of 0.8, it has too few neutrons. It would undergo positron (β^+) emission or electron capture to increase this ratio.

$^{32}_{16}$S

For this nuclide, Z = 16 and N = (32 – 16) = 16. With an N:Z ratio of 1.0, it is probably stable.

$^{236}_{90}$Th

As Z > 83, it is beyond the zone of stability and is unstable. It will indergoes α decay to reduce its mass.

Marks

- The ^{14}C specific activity of a tooth found in an archaeological dig is 0.34 Bq. The ^{14}C specific activity in living organisms is 15.3 Bq. How old is the tooth? **4**

The ^{14}C age is given by:

$$^{14}\text{C age} = 8033 \ln\frac{A_0}{A_t}$$

Hence,

$$^{14}\text{C age} = 8033 \ln\left(\frac{15.3}{0.34}\right) = 31000 \text{ years}$$

Answer: **31000 years**

Give two reasons why the accuracy of radiocarbon dating is more uncertain for older objects.

The very low activities of very old objects means that errors in measurement are proportionally more significant.

Small amounts of contamination from modern organic material may have a larger proportional effect on the activity of older samples.

- Why are positron emitters the best type of radioisotope to use for tomography? **2**

Positrons immediately annihilate when they collide with their antiparticles (electrons) and produce 2 gamma rays that propagate in opposite directions.

These are easily detected and, with the aid of computers, allow determination of the line along which the source must have been.

Statistical repetition allows a 3-dimensional image to be generated.

- Explain the following terms or concepts.

Marks 3

a) Lipid bilayer

A 2-dimensional self-assembled structure consisting of two layers of lipids with their non-polar (hydrophobic) tails pointing inwards and their polar (hydrophilic) heads at the interface with the solution.

b) Oxidation number

The charge an atom would have if all the electrons involved in covalent bonds were allocated to the more electronegative of the 2 atoms they are shared between.

c) Electrolysis

The process of forcing a non-spontaneous redox reaction to occur by providing sufficient energy in the form of an applied electrical potential.

- Write balanced nuclear equations for the following reactions. **2**

Beta decay of nickel-66.

$${}^{66}_{28}\text{Ni} \rightarrow {}^{66}_{29}\text{Cu} + {}^{0}_{-1}\text{e}$$

Electron capture of selenium-72

$${}^{72}_{34}\text{Se} + {}^{0}_{-1}\text{e} \rightarrow {}^{72}_{33}\text{As} + \text{X-rays}$$

Marks

- A medical procedure requires 15.0 mg of ^{111}In. What mass of isotope would be required to be able to use it exactly 4 days later? The half life of ^{111}In is 2.80 days. **2**

With a half life, $t_{1/2}$ = 2.80 days, the activity coefficient, λ, is:

$$\lambda = \ln 2/t_{1/2} = (\ln 2/2.80) \text{ days}^{-1} = 0.248 \text{ days}^{-1}$$

The amount of isotope at time t is related to the initial amount using $\ln(N_0/N_t) = \lambda t$. With N_t = 15.0 mg left after t = 4 days, the initial mass required is therefore:

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

$$\ln(N_0 / 15.0) = (0.248 \text{ days}^{-1}) \times (4 \text{ days})$$

$$N_0 = 40.4 \text{ mg}$$

Answer: **40.4 mg**

- Write balanced nuclear equations for the following reactions. **3**

Positron decay of potassium-40.

$$^{40}_{19}K \rightarrow {}^{40}_{18}Ar + {}^{0}_{+1}e$$

Electron capture by gallium-67.

$$^{67}_{31}Ga + {}^{0}_{-1}e \rightarrow {}^{67}_{30}Zn$$

Alpha decay of dysprosium-151.

$$^{151}_{66}Dy \rightarrow {}^{147}_{64}Gd + {}^{4}_{2}He$$

- Briefly explain the apparent contradiction between the following statements. **1**

"Alpha particles are easily stopped by the skin."
"The alpha-emitter, radon, is thought to be a significant cause of cancer."

Radon is a gas, so can be inhaled. The alpha particles are therefore generated in the lungs and can cause direct damage without needing to penetrate the skin.

Marks 3

- Strontium-90 is one of the harmful nuclides resulting from nuclear fission explosions. Strontium-90 decays by beta particle emission with a half-life of 28.0 years. How long (in years) would it take for 99.0% of a sample of strontium-90 released in an atmospheric test of an atomic bomb to decay?

The number of nuclei at time t , N_t, is related to the number of nuclei present at t = 0, N_0 by:

$$\ln\left(\frac{N_0}{N_t}\right) = \lambda t$$

where λ is the activity constant.

The half life, $t_{1/2}$, corresponds to the time required for half of the sample to decay: $\frac{N_0}{N_t}$ = 2 and so $t_{1/2} = \frac{\ln 2}{\lambda}$. Hence, $\lambda = \frac{\ln 2}{t_{1/2}}$

If 99.0% of the sample has decayed, 1.0% is remaining and so $\frac{N_0}{N_t} = \frac{100}{1}$:

$$\ln\left(\frac{100}{1}\right) = \frac{\ln 2}{(28.0 \text{ years}^{-1})} \times t \quad \text{or } t = 186 \text{ years.}$$

Answer: **186 years**

Marks 7

- A cyclotron facility can produce beams of neutrons or protons. Theoretically, $^{188}_{75}Re$ can be produced by irradiation of $^{186}_{74}W$ with either particle followed by radioactive decay of the intermediate nuclide. Give the relevant equations to describe both sequences of reactions.

neutron bombardment

$$^{186}_{74}W + ^{1}_{0}n \rightarrow ^{187}_{74}W$$

$$^{187}_{74}W + ^{1}_{0}n \rightarrow ^{188}_{74}W$$

$$^{188}_{74}W \rightarrow ^{188}_{75}Re + ^{0}_{-1}e \quad \textbf{(beta decay)}$$

proton bombardment

$$^{186}_{74}W + ^{1}_{1}p \rightarrow ^{187}_{75}Re$$

$$^{187}_{75}W + ^{1}_{1}p \rightarrow ^{188}_{76}Os$$

$$^{188}_{76}Os \rightarrow ^{188}_{75}Re + ^{0}_{1}p \quad \textbf{(positron emission)}$$

In practice, only the sequence using neutron bombardment is used. Give one possible reason why proton bombardment is not used.

Energy required to add positively charged protons to nucleus is large.

Intermediate in proton bombardment ($^{188}_{76}Os$) is stable.

THE ANSWER CONTINUES ON THE NEXT PAGE

Rhenium-188 is used for the relief of cancer-induced bone pain and has a half life of 16.7 hours. What mass of $^{188}_{75}Re$ needs to be produced to allow shipment 24 hours later of a solution with a specific activity of 500 mCi?

The decay constant is related to the half life as $t_{1/2} = \frac{\ln 2}{\lambda}$. Thus,

$$\lambda = \frac{\ln 2}{(16.7 \times 60 \times 60\,s)} = 1.15 \times 10^{-5}\ s^{-1}$$

As $A = \lambda N$, the activity of one mole is,

$$A_m = (1.15 \times 10^{-5}) \times (6.022 \times 10^{23})$$

$$= 6.94 \times 10^{18}\ Bq\ mol^{-1} = \frac{6.94 \times 10^{18}}{3.70 \times 10^{10}} = 1.88 \times 10^{8}\ Ci\ mol^{-1}$$

For ^{188}Re, the atomic mass = 188 and hence the activity per gram is,

$$A_g = \frac{1.88 \times 10^{8}}{188} = 1.00 \times 10^{6}\ Ci\ g^{-1}$$

As the number of nuclei is proportional to the activity, the activity decreases with time according to the equation,

$$\ln\left(\frac{A_0}{A_t}\right) = \lambda t$$

Hence, if A = 500 mCi after 24 hours,

$$\ln\left(\frac{A_0}{500 \times 10^{-3}}\right) = (1.15 \times 10^{-5}) \times (24 \times 60 \times 60)$$

$$A_0 = 1.35\ Ci$$

Hence,

$$\text{mass required} = \frac{\text{activity required}}{\text{activity per gram}} = \frac{A_0}{A_g} = \frac{1.35}{1.00 \times 10^{6}}$$

$$= 1.35 \times 10^{-6}\ g = 1.35\ \mu g$$

Answer: **1.35 μg**

Marks 2

- If a medical procedure calls for 2.0 mg of ^{48}V, what mass of isotope would be required to be able to use it exactly one week later? The half life of ^{48}V is 1.61 days.

The decay constant is related to the half life as $t_{1/2} = \frac{\ln 2}{\lambda}$. Thus,

$$\lambda = \frac{\ln 2}{1.61} = 0.431 \text{ days}^{-1}$$

The number of radioactive nuclei decreases with time according to the equation,

$$\ln\left(\frac{N_0}{N_t}\right) = \lambda t$$

If N_t = 2.0 mg after t = 7 days,

$$\ln\left(\frac{N_0}{2.0\times10^{-3}}\right) = (0.431) \times 7.00 \qquad \text{so } N_0 = 0.041 \text{ g} = 41 \text{ mg}$$

Answer: **41 mg**

Marks 2

- If a medical procedure calls for 1.0 mg of ^{128}Ba, how much isotope would be required to be able to use it exactly one week later? The half life of ^{128}Ba is 2.43 days.

The decay constant, λ, is related to the half life, $\lambda = \frac{\ln 2}{t_{1/2}} = \frac{\ln 2}{2.43 \text{ days}} = 0.285$ days^{-1}. The number of radioactive nuclei present reduces with time according to:

$$\ln\left(\frac{N_0}{N_t}\right) = \lambda t$$

With a decay constant, λ = 0.285 days, and N_t = 1.0 mg for t = 7 days, the amount originally present would have to be:

$$\ln\left(\frac{N_0}{(1.0\times10^{-3}\text{ g})}\right) = 0.285 \times 7$$

N_0 = 0.0074 g = 7.4 mg

Answer: **7.4 mg**

Marks 2

- A watch contains a radioactive substance with a decay constant of 1.40×10^{-2} year^{-1}. After 50 years 25 mg of the radioactive material remains. Calculate the amount originally present.

The number of radioactive nuclei present reduces with time according to:

$$\ln\left(\frac{N_0}{N_t}\right) = \lambda t$$

With a decay constant, $\lambda = 1.4 \times 10^{-2}$ year^{-1}, and $N_t = 25$ mg for t = 50 years, the amount originally present is given by:

$$\ln\left(\frac{N_0}{(25 \times 10^{-3})}\right) = (1.4 \times 10^{-2}) \times 50$$

$N_0 = 0.050$ g = 50 mg

Answer: **50 mg**

- Briefly explain why a radionuclide used in diagnostic work should have a short half-life. **2**

The half life should be short enough to rid the body of radioactivity before damage occurs. (It must also be long enough to allow the compound containing the radionuclide to be made and administered).

- Briefly explain why alpha emitters are not used in diagnostic work. **2**

Because of their high mass and charge, alpha particles interact strongly with tissue and cause potentially damaging ionization if inside the body.