A solution of sodium iodide containing the radioisotope $^{131}$I has an activity of 20 mCi L$^{-1}$ when freshly prepared. Fifteen days later, a patient is given 0.50 mL of this solution. Calculate the dose of $^{131}$I (in microcurie, µCi) received by the patient. The half-life of $^{131}$I is 8.04 days.

The decay constant, $\lambda$, is related to the half-life, $\lambda = \frac{\ln 2}{t_{1/2}} = \frac{\ln 2}{8.04 \text{ days}} = 0.0862$ days$^{-1}$

The activity is proportional to the number of radioactive nuclei, $A = \lambda N$, and the activity reduces with time according to:

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

With an initial activity of 20 mCi L$^{-1}$, the activity after 15 days is given by,

$$\ln \left( \frac{20 \times 10^{-3} \text{ mCi L}^{-1}}{A_t} \right) = (0.0862) \times 15$$

Hence $A_t = 0.00549 \text{ Ci L}^{-1} = 5.49 \text{ mCi L}^{-1}$

Hence, a solution of 0.50 mL will have a dosage of:

$$\text{dosage} = \text{activity} \times \text{volume}$$

$$= (5.49 \times 10^{-3} \text{ mCi L}^{-1}) \times (\frac{0.50}{1000} \text{ L}) = 2.7 \times 10^{-6} \text{ Ci} = 2.7 \mu\text{Ci}$$

Answer: 2.7 µCi
Give three examples of colloids in biological systems, and complete the following table. Paint is given as an example of a synthetic (non-biological) system.

<table>
<thead>
<tr>
<th>Name of colloid</th>
<th>Discrete phase</th>
<th>Continuous phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>paint</td>
<td>synthetic polymer</td>
<td>water</td>
</tr>
<tr>
<td>blood</td>
<td>red blood cells</td>
<td>water/plasma</td>
</tr>
<tr>
<td>milk</td>
<td>casein</td>
<td>water</td>
</tr>
<tr>
<td>cell</td>
<td>nucleus, ribosomes etc</td>
<td>cell fluid/ctyoplasm</td>
</tr>
</tbody>
</table>

One of the components of bile acid is sodium deoxycholate, whose structure is given below.

Sodium deoxycholate is an electrostatic stabiliser.

The organic rings are hydrophobic. This part of the molecule is adsorbed onto the surface of the fat whilst the hydrophilic carboxylate group is in contact with the surrounding water. The solubilised fat is stabilised in the water by the double layer of repulsion charges that prevents coagulation.
Give three examples of colloids in biological systems, and complete the following table. Paint is given as an example of a synthetic (non-biological) system.

<table>
<thead>
<tr>
<th>Name of colloid</th>
<th>Discrete phase</th>
<th>Continuous phase</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>paint</em></td>
<td><em>synthetic polymer</em></td>
<td><em>water</em></td>
</tr>
<tr>
<td><em>blood</em></td>
<td><em>red blood cells</em></td>
<td><em>water/plasma</em></td>
</tr>
<tr>
<td><em>milk</em></td>
<td><em>casein</em></td>
<td><em>water</em></td>
</tr>
<tr>
<td><em>cell</em></td>
<td><em>nucleus, ribosomes etc</em></td>
<td><em>cell fluid/ctyoplasm</em></td>
</tr>
</tbody>
</table>

Alginates are high molecular weight polysaccharides extracted from seaweed. The surface active agent with the common name "propylene glycol alginate" is used as a thickener in foodstuffs. It is made by esterifying approximately 80% of the carboxyl units of the polysaccharide with 1,2-propanediol depicted, in part, below.

Explain in terms of its two components (the polysaccharide and 1,2-propanediol) why the ester functions as (a) a surfactant and (b) a thickener.

(a) The ester acts as a surfactant because the polymer contains both hydrophobic regions (C–H) and hydrophilic regions (O–H, COOH). The hydrophobic areas adhere to greasy particles and the hydrophilic areas allow dispersal into aqueous medium.

(b) The long chains of the polymer are dispersed in the water. This disrupts the free flow of the water molecules which in turn increases the viscosity of the solution.
A watch contains a radioactive substance with a decay constant of $1.4 \times 10^{-2}$ 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:

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

$N_0 = 0.050$ g = 50 mg

Answer: 50 mg
• Technetium-99 is used in imaging internal organs in the body, and is often used to assess heart damage. The rate constant for decay of $^{99m}_{43}$Tc is 0.116 hour$^{-1}$. What is the half life of this nuclide?

The half life is related to the decay constant, $\lambda$:

$$t_{1/2} = \frac{\ln 2}{\lambda} = \frac{\ln 2}{0.116 \text{ hours}^{-1}} = 5.98 \text{ hours}$$

Answer: 5.98 hours

What fraction is left after 30 minutes?

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

$$\ln \left( \frac{N_0}{N_t} \right) = \lambda t = 0.116 \times \frac{30}{60} \text{ so } \frac{N_0}{N_t} = 1.06$$

Hence, 6% has decay and the fraction remaining is 94%

Answer: 94%

• Boron-13 is a synthetic (not naturally occurring) isotope of boron. Using the $N/Z$ ratio, predict a possible mode of decay for the isotope boron-13. Give a reason for your choice and write the nuclear equation for this decay.

The most stable nuclei tend to have $N \sim Z$.

$^{13}$B has 8 neutrons and 5 protons. As $N > Z$, the nucleus has too many neutrons and will decay by beta decay: conversion of a neutron into a proton and an electron:

$$^{13}_5 \text{B} \rightarrow ^{13}_6 \text{C} + ^0_{-1} \text{e}$$
Consider the following reaction.

\[ 2\text{ClO}_2(\text{aq}) + 2\text{OH}^-(\text{aq}) \rightarrow \text{ClO}_3^-(\text{aq}) + \text{ClO}_2^-(\text{aq}) + \text{H}_2\text{O}(\text{l}) \]

A series of experiments gave the rate data shown in the table below.

<table>
<thead>
<tr>
<th>Experiment number</th>
<th>initial [\text{ClO}_2] (M)</th>
<th>initial [\text{OH}^-] (M)</th>
<th>initial rate of decrease of [\text{ClO}_2] (M s(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0500</td>
<td>0.100</td>
<td>5.75 \times 10^{-2}</td>
</tr>
<tr>
<td>2</td>
<td>0.100</td>
<td>0.100</td>
<td>2.30 \times 10^{-1}</td>
</tr>
<tr>
<td>3</td>
<td>0.100</td>
<td>0.050</td>
<td>1.15 \times 10^{-1}</td>
</tr>
</tbody>
</table>

Determine the rate expression for the above reaction.

Between experiments 1 and 2, [\text{OH}^-] is kept constant. [\text{ClO}_2] is doubled and this quadruples the rate: the reaction is second order with respect to [\text{ClO}_2].

Between experiments 2 and 3, [\text{ClO}_2] is kept constant. [\text{OH}^-] is halved and this halves the rate: the reaction is first order with respect to [\text{OH}^-]. Thus,

\[ \text{rate} \alpha \text{[ClO}_2]^2\text{[OH}^-] = k\text{[ClO}_2]^2\text{[OH}^-] \]

What is the value of the rate constant? Include units in your answer.

Using experiment 1,

\[ \text{rate} = k\text{[ClO}_2]^2\text{[OH}^-] \]

\[ (5.75 \times 10^{-2} \text{ M s}^{-1}) = k \times (0.0500 \text{ M})^2 \times (0.100 \text{ M}) \quad \text{so} \quad k = 230 \text{ M}^2 \text{ s}^{-1} \]

\[ (\text{M s}^{-1}) = \text{(units of } k) \times (\text{M})^2 \times (\text{M}) \quad \text{so the units of } k \text{ are } \text{M}^2 \text{ s}^{-1} \]

\[ k = 230 \text{ M}^2 \text{ s}^{-1} \]

What is the relationship between the rate of decrease of [\text{ClO}_2] and the rate of increase of [\text{ClO}_3^-]? From the chemical equation, two moles of \text{ClO}_2 are lost for every mole of \text{ClO}_3^- formed. Thus, the rate of decrease of [\text{ClO}_2] is twice the rate of increase of [\text{ClO}_3^-] (or the rate of increase of [\text{ClO}_3^-] is half the rate of decrease of [\text{ClO}_2]).
It has been proposed that the reaction $\text{Cl}_2(g) + \text{CHCl}_3(g) \rightarrow \text{HCl}(g) + \text{CCl}_4(g)$ proceeds by the following mechanism:

$$\text{Cl}_2(g) \xrightleftharpoons[k{-}1]{k_1} 2\text{Cl}(g) \quad \text{(fast equilibrium)}$$

$$\text{Cl}(g) + \text{CHCl}_3(g) \xrightarrow{k_2} \text{HCl}(g) + \text{CCl}_3(g) \quad \text{(slow)}$$

$$\text{CCl}_3(g) + \text{Cl}(g) \xrightarrow{k_3} \text{CCl}_4(g) \quad \text{(fast)}$$

Derive the rate expression for this mechanism.

As the second reaction is slow, it is rate determining. From the mechanism, the rate of this step is given by:

$$\text{rate} = k_2[\text{Cl}(g)][\text{CHCl}_3(g)]$$

As Cl is a highly reactive intermediate, its concentration cannot be included in the rate equation which is to be experimental tested. As the first step is fast, the equilibrium between $\text{Cl}_2(g)$ and Cl(g) will be set up rapidly and maintained for most of the reaction. For an equilibrium,

$$\text{rate forward reaction} = \text{rate backward reaction}$$

$$k_1[\text{Cl}_2(g)] = k_{-1}[\text{Cl}(g)]^2$$

or $[\text{Cl}(g)]^2 = \frac{k_1}{k_{-1}}[\text{Cl}_2(g)]$

Hence,

$$\text{rate} = k_2[\text{Cl}(g)][\text{CHCl}_3(g)] = k_2 \times \sqrt[2]{\frac{k_1}{k_{-1}}[\text{Cl}_2(g)]} \times [\text{CHCl}_3(g)]$$

$$= k_2 \sqrt[2]{\frac{k_1}{k_{-1}}}[\text{CHCl}_3(g)][\text{Cl}(g)]^{1/2} = k[\text{CHCl}_3(g)][\text{Cl}(g)]^{1/2}$$

where $k = k_2 \sqrt[2]{\frac{k_1}{k_{-1}}}$

Answer: rate $= k[\text{CHCl}_3(g)][\text{Cl}(g)]^{1/2}$

THE REMAINDER OF THIS PAGE IS FOR ROUGH WORKING ONLY.