CHEM1612 Answers to Problem Sheet 10

1. **For *light* nuclei, the most nuclides tend to have $N \sim Z$.**

If $N > Z$, the nucleus has too many neutrons (and decay by beta decay: conversion of a neutron into a proton and an electron).

If $N < Z$, the nucleus has either too many protons (and decay by positron emission: conversion of a proton into a neutron and a positron) or has too few neutrons (and undergo electron capture: conversion of an electron and a proton into a neutron). Electron capture is rare for natural isotopes.

For $Z > 82$, alpha decay is preferred.

(a) ^{19}Ne – **10 protons and 9 neutrons**
^{20}Ne – **10 protons and 10 neutrons**
^{23}Ne – **10 protons and 13 neutrons**

As ^{20}Ne has $N = Z$, it is the most stable.

^{19}Ne has too few neutrons as $N < Z$:

$^{19}_{10}\text{Ne} \rightarrow {}^{19}_{9}\text{F} + {}^{0}_{+1}\text{e}$ **(positron emission)**

$^{19}_{10}\text{Ne} + {}^{0}_{-1}\text{e} \rightarrow {}^{19}_{9}\text{F}$ + **X-rays** **(electron capture)**

^{23}Ne has too many neutrons $N > Z$:

$^{23}_{10}\text{Ne} \rightarrow {}^{23}_{11}\text{Na} + {}^{0}_{-1}\text{e}$ **(beta emission)**

For heavier nuclei, additional neutrons are required and the acceptable N / Z ratio exceeds 1.

(b) ^{58}Ni – **28 protons and 30 neutrons**
^{59}Ni – **28 protons and 31 neutrons**
^{66}Ni – **28 protons and 38 neutrons**

The $N : Z$ ratio is slightly greater than 1 for ^{58}Ni and ^{59}Ni, as required for heavier nuclides, and both are possible candidates.

^{66}Ni has $N >> Z$ and is unstable

$^{66}_{28}\text{Ni} \rightarrow {}^{66}_{29}\text{Cu} + {}^{0}_{-1}\text{e}$ **(beta emission)**

$^{66}_{29}$Cu still has $N : Z$ = 37:29 so will undergo further beta decay.

2. **The non-ionizing radiation can be neglected. The key factors are the rate of decay and the energy of the ionizing particles.**

In each case, the decay constant is given by $\lambda = \dfrac{\ln 2}{t_{1/2}}$. If the ionizing radiation has energy E then the amount of energy delivered by the ionizing radiation each year is given by

$$\text{amount of energy per year} = E \times \lambda$$

For $^{238}_{94}Pu \rightarrow \alpha\ (5.50\ MeV) + \gamma\ (0.044\ MeV) + {}^{234}_{92}U$ ($t_{½}$ = 87.7 years), the γ-ray is ionizing. The decay constant is:

$$\lambda = \frac{\ln 2}{87.7\ \text{years}} = 7.90 \times 10^{-3}\ \text{years}^{-1}$$

Hence,

$$\text{amount of energy per year} = (0.044\ \text{MeV}) \times (7.90 \times 10^{-3}\ \text{years}^{-1}) = 3.48 \times 10^{-4}\ \text{MeV years}^{-1}$$

For $^{238}_{94}Pu \rightarrow \alpha\ (5.16\ MeV) + \gamma\ (0.374\ MeV) + {}^{235}_{92}U$ ($t_{½}$ = 2.41 × 10^4 years), the γ-ray is ionizing. The decay constant is:

$$\lambda = \frac{\ln 2}{(2.41 \times 10^4\ \text{years})} = 2.88 \times 10^{-5}\ \text{years}^{-1}$$

Hence,

$$\text{amount of energy per year} = (0.374\ \text{MeV}) \times (2.88 \times 10^{-5}\ \text{years}^{-1}) = 1.08 \times 10^{-5}\ \text{MeV years}^{-1}$$

For $^{240}_{94}Pu \rightarrow \alpha\ (5.26\ MeV) + \gamma\ (0.104\ MeV) + {}^{236}_{92}U$ ($t_{½}$ = 6537 years), the γ-ray is ionizing. The decay constant is:

$$\lambda = \frac{\ln 2}{6537\ \text{years}} = 1.06 \times 10^{-4}\ \text{years}^{-1}$$

Hence,

$$\text{amount of energy per year} = (0.104\ \text{MeV}) \times (1.06 \times 10^{-4}\ \text{years}^{-1}) = 1.10 \times 10^{-5}\ \text{MeV years}^{-1}$$

For $^{241}_{94}Pu \rightarrow \beta^-\ (4.85\ MeV) + \gamma\ (0.149\ MeV) + {}^{242}_{95}Am$ ($t_{½}$ = 14.4 years), the γ-ray is ionizing. The decay constant is:

$$\lambda = \frac{\ln 2}{14.4\ \text{years}} = 0.0481\ \text{years}^{-1}$$

Hence,

$$\text{amount of energy per year} = (0.149 \text{ MeV}) \times (0.0481 \text{ years}^{-1}) = 7.17 \times 10^{-3} \text{ MeV years}^{-1}$$

For $^{242}_{94}Pu \rightarrow \alpha\ (4.98\ \text{MeV}) + \gamma\ (0.104\ \text{MeV}) + {}^{238}_{92}U\ (t_{½} = 3.76 \times 10^5\ \text{years})$, the γ-ray is ionizing. The decay constant is:

$$\lambda = \frac{\ln 2}{(3.76 \times 10^5 \text{years})} = 1.84 \times 10^{-6} \text{ years}^{-1}$$

Hence,

$$\text{amount of energy per year} = (0.104 \text{ MeV}) \times (1.84 \times 10^{-6} \text{ years}) = 1.92 \times 10^{-7} \text{ MeV years}^{-1}$$

The ranking is therefore that shown below with $^{241}_{94}Pu$ much more harmful than the others. $^{239}_{94}Pu$ and $^{240}_{94}Pu$ are likely to be of very similar harm to organisms.

	Ranking
$^{238}_{94}Pu \rightarrow \alpha\ (5.50\ \text{MeV}) + \gamma\ (0.044\ \text{MeV}) + {}^{234}_{92}U\ (t_{½} = 87.7\ \text{years})$	**2**
$^{239}_{94}Pu \rightarrow \alpha\ (5.16\ \text{MeV}) + \gamma\ (0.374\ \text{MeV}) + {}^{235}_{92}U\ (t_{½} = 2.41 \times 10^4\ \text{years})$	**3**
$^{240}_{94}Pu \rightarrow \alpha\ (5.26\ \text{MeV}) + \gamma\ (0.104\ \text{MeV}) + {}^{236}_{92}U\ (t_{½} = 6537\ \text{years})$	**4**
$^{241}_{94}Pu \rightarrow \beta^-\ (4.85\ \text{MeV}) + \gamma\ (0.149\ \text{MeV}) + {}^{242}_{95}Am\ (t_{½} = 14.4\ \text{years})$	**1**
$^{242}_{94}Pu \rightarrow \alpha\ (4.98\ \text{MeV}) + \gamma\ (0.104\ \text{MeV}) + {}^{238}_{92}U\ (t_{½} = 3.76 \times 10^5\ \text{years})$	**5**

3. **$^{15}_{7}N$ is formed by positron emission from ^{15}O: $^{15}_{8}O \rightarrow {}^{15}_{7}N + {}^{0}_{+1}e$**

4. **As number of nuclei left after a time t is related to the initial amount and the decay constant by:**

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

If the concentration of ^{131}I is 10% of its initial value then $\frac{N_0}{N_t} = \frac{100}{10}$. Hence, with $\lambda = 0.086\ \text{day}^{-1}$,

$$\ln\left(\frac{100}{10}\right) = (0.086 \text{ days}^{-1}) \times t \quad \text{so } t = 27 \text{ days}$$

5.

Example	Dispersed phase	Dispersing system	Name of colloid system
Shaving cream	**gas**	**liquid**	**foam**
Fog	**liquid**	**gas**	**liquid aerosol**
Toothpaste	**solid**	**liquid**	**sol**
Styrofoam	**gas**	**solid**	**solid foam**

6. **The main constituent of cell walls is the phospholipids.**

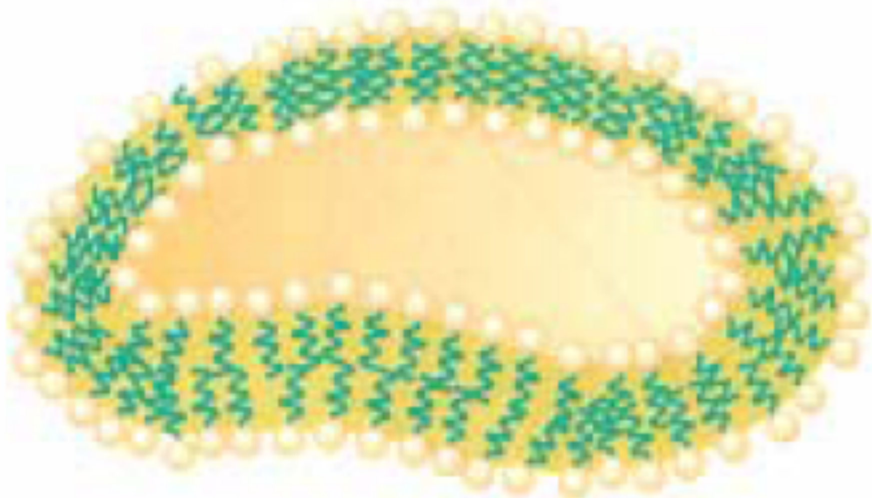
Phospholipids are similar in structure to fats in that they are esters of glycerol. However unlike fats they contain only two fatty acids. The third ester linkage involves a phosphate group, which gives phospholipids two distinct parts:

- **long non-polar tail**
- **polar substituted phosphate "head"**

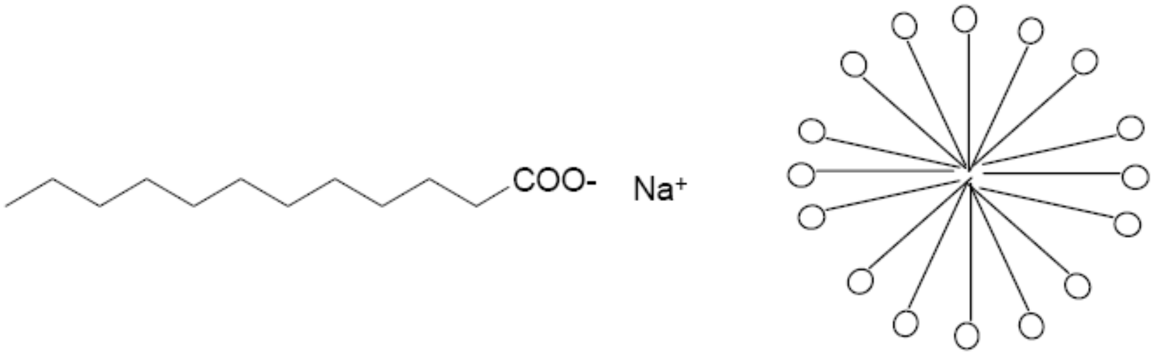
Phospholipids tend to form bilayers in aqueous solution with the tails in the interior and the polar heads interfacing with the polar water molecules.

The bilayers of larger phospholipids can close to form *vesicles.*

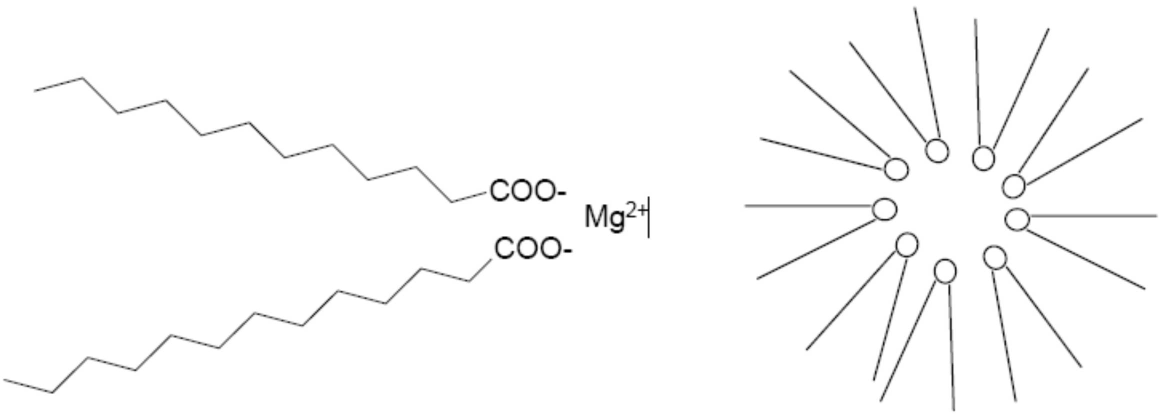
Schematic of a cell:



7. **Typical soaps are salts of carboxylic acids. When mixed with water, they can stabilise either water-in-oil or oil-in-water emulsions, depending on the counter ion. A monovalent cation will interact closely with only one chain, giving a roughly cylindrical. aggregate that can pack to form oil-in water emulsions:**



While a divalent cation will interact closely with two chains, giving an aggregate that is larger at the hydrophobic end than the hydrophilic end and can pack readily only to form water in oil emulsions:



Accordingly, soaps will function less effectively in so-called 'hard' water containing Mg^{2+} or Ca^{2+}.