# National 5 Chemistry

## Unit 1:

### Chemical Changes & Structure

### Topic 2

#### Atomic Chemistry

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</tr>
<tr>
<td></td>
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### Consolidation Work

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### End-of-Unit Assessment

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</tbody>
</table>
2.1 Atomic Structure

This lesson topic revises and extends your understanding of Atomic Structure.

Atomic Models

**Dalton Model**

Early models of the atom imagined hard indestructible spheres similar to "Snooker Balls" colliding and bouncing off each other. This Model remains effective as part of our **Particle Model of Matter**.

**Thompson Model**

Scientists such as **JJ Thompson** were able to show, firstly, that atoms contained very small negatively charged particles (**electrons**) and later that they also contained positive particles (**protons**). The "Plum Pudding" model.

**Rutherford Model**

**Rutherford** then showed that all the protons were concentrated in a tiny **nucleus** in the centre of the atom. and that over 99% of an atom was empty space. Finally the presence of neutral particles (**neutrons**) was proven.

**Bohr Model**

**Bohr** put forward the theory that electrons orbited the nucleus in shells rather like planets around the sun. This is the model most often used, though we now know that electrons do not move like this.

**Cloud Model**

We can also imagine electrons occupying cloud-like regions in space called "**orbitals**". This model is particularly useful when trying to visualise the shape of molecules and when dealing with multiple bonds.

**SUMMARY**

3 types of particles; **protons** (+ve), **neutrons** and **electrons** (–ve).

The protons and neutrons are squashed together in the nucleus. The nucleus is extremely small, heavy and positively charged.

The electrons 'move' around the nucleus in a complex pattern.
Important Numbers

**Atomic Number** - is the number of protons in the nucleus of all atoms in an element.

**Mass Number** - is the total number of protons and neutrons in the nucleus of an atom.

**Electrons** - In neutral atoms the number of electrons is equal to the number of protons so we can usually use the Atomic Number to tell us the number of electrons as well.

**Neutrons** - The number of neutrons is simply the number of protons (Atomic Number) subtracted from the Mass Number.

Each element has a different atomic number and they are listed in order of this number. Elements with similar properties are found in the same group.
<table>
<thead>
<tr>
<th>Element</th>
<th>Symbol</th>
<th>Atomic Number</th>
<th>Mass Number</th>
<th>number of protons</th>
<th>number of electrons</th>
<th>number of neutrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>N</td>
<td>7</td>
<td>14</td>
<td>7</td>
<td>7</td>
<td>14 - 7 = 7</td>
</tr>
<tr>
<td>Oxygen</td>
<td>O</td>
<td>8</td>
<td>16</td>
<td>8</td>
<td>8</td>
<td>16 - 8 = 8</td>
</tr>
<tr>
<td>Neon</td>
<td>Ne</td>
<td>10</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>20 - 10 = 10</td>
</tr>
<tr>
<td>Sodium</td>
<td>Na</td>
<td>11</td>
<td>23</td>
<td>11</td>
<td>11</td>
<td>23 - 11 = 12</td>
</tr>
<tr>
<td>Magnesium</td>
<td>Mg</td>
<td>12</td>
<td>24</td>
<td>12</td>
<td>12</td>
<td>24 - 12 = 12</td>
</tr>
<tr>
<td>Silicon</td>
<td>Si</td>
<td>14</td>
<td>28</td>
<td>14</td>
<td>14</td>
<td>28 - 14 = 14</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>P</td>
<td>15</td>
<td>31</td>
<td>15</td>
<td>15</td>
<td>31 - 15 = 16</td>
</tr>
<tr>
<td>Sulfur</td>
<td>S</td>
<td>16</td>
<td>32</td>
<td>16</td>
<td>16</td>
<td>32 - 16 = 16</td>
</tr>
<tr>
<td>Potassium</td>
<td>K</td>
<td>19</td>
<td>39</td>
<td>19</td>
<td>19</td>
<td>39 - 19 = 20</td>
</tr>
<tr>
<td>Nickel</td>
<td>Ni</td>
<td>28</td>
<td>59</td>
<td>28</td>
<td>28</td>
<td>59 - 28 = 21</td>
</tr>
<tr>
<td>Zinc</td>
<td>Zn</td>
<td>30</td>
<td>66</td>
<td>30</td>
<td>30</td>
<td>66 - 30 = 36</td>
</tr>
<tr>
<td>Silver</td>
<td>Ag</td>
<td>47</td>
<td>108</td>
<td>47</td>
<td>47</td>
<td>108 - 47 = 61</td>
</tr>
<tr>
<td>Tin</td>
<td>Sn</td>
<td>50</td>
<td>119</td>
<td>50</td>
<td>50</td>
<td>119 - 50 = 69</td>
</tr>
<tr>
<td>Platinum</td>
<td>Pt</td>
<td>78</td>
<td>195</td>
<td>78</td>
<td>78</td>
<td>195 - 78 = 117</td>
</tr>
<tr>
<td>Mercury</td>
<td>Hg</td>
<td>80</td>
<td>201</td>
<td>80</td>
<td>80</td>
<td>201 - 80 = 120</td>
</tr>
</tbody>
</table>

Number of protons = Atomic Number

Number of electrons = Number of protons = Atomic Number

Number of neutrons = Total in nucleus - Number of protons = Mass Number - Atomic Number

The Mass Number can only ever refer to one particular atom. However, when we want to talk generally about the mass of the atoms of an element, we can usually safely assume that the average mass (RAM) rounded to the nearest whole number can safely be used as the 'most likely' Mass Number for an atom of this element - but be careful, Br has RAM 79.9 so we would assume 'most likely' Mass Number = 80, but only $^{79}$Br and $^{81}$Br exist naturally.
**Iso**topes are atoms of the same element which have the same number of protons but have different numbers of neutrons.

This means that atoms of the same element can have different masses.

Since atoms of the same element can have different masses, it is necessary to know the average mass - the relative atomic mass of an element.

Information provided by a machine called a mass spectrometer can be used to calculate the RAM of an element.
① Each *atom* has an *electron* knocked off which leaves the atom as a *positively* charged *ion*.

② The *ions* are *accelerated* by an *electric* field; repelled by a *positive* plate, attracted towards a *negative*.

③ The strength of the *magnetic* field is gradually *increased*.

④ Any *ions* that are of the correct *mass* will be deflected ‘round the corner’.

⑤ Any *ions* which are still too *heavy* for the *magnetic* field will crash into the wall of the chamber. They will be *detected* later when the field is *stronger*.

⑥ Any *ions* which are too *light* will be deflected too far. They would have been *detected* earlier when the field was *weaker*.

⑦ Any *ions* arriving here are *detected* and *counted*.

The *mass spectrometer* is able to tell us 3 things about an element:

1. the *number* of *isotopes* that element has,
2. the *mass number* of each *isotope*, and
3. the *relative amounts* of each *isotope*.

The information is printed out in the form of a *mass spectrum*.
From this information it is now possible to calculate the average mass of all the atoms in the element.

\[
\text{RAM} = \frac{\text{mass}_1 \times \%_1 + \text{mass}_2 \times \%_2}{100}
\]

\[
= \frac{(35 \times 75) + (37 \times 25)}{100}
\]

\[
= \frac{(2625) + (925)}{100}
\]

\[
= \frac{3550}{100} = 35.5 \text{ amu}
\]

<table>
<thead>
<tr>
<th>Atomic No. (Z)</th>
<th>Name</th>
<th>Symbol</th>
<th>% Abundance</th>
<th>RAM (Relative Atomic Mass)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Lithium</td>
<td>(^6\text{Li})</td>
<td>7.59</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(^7\text{Li})</td>
<td>92.41</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Boron</td>
<td>(^{10}\text{B})</td>
<td>19.90</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(^{11}\text{B})</td>
<td>80.10</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Magnesium</td>
<td>(^{24}\text{Mg})</td>
<td>78.99</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(^{25}\text{Mg})</td>
<td>10.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(^{26}\text{Mg})</td>
<td>11.01</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Silicon</td>
<td>(^{28}\text{Si})</td>
<td>92.23</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(^{29}\text{Si})</td>
<td>4.68</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(^{30}\text{Si})</td>
<td>3.09</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>Chromium</td>
<td>(^{50}\text{Cr})</td>
<td>4.35</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(^{52}\text{Cr})</td>
<td>83.79</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(^{53}\text{Cr})</td>
<td>9.50</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(^{54}\text{Cr})</td>
<td>2.36</td>
<td></td>
</tr>
</tbody>
</table>

* Some values within this table have been rounded / modified for simplicity.
Isotopic Ions

It is not just the **number of neutrons** that can be different in atoms of the **same element**. Atoms can also change their **number of electrons**.

\[
\begin{align*}
7_3^{\text{Li}} & \quad 6_3^{\text{Li}} & \quad 7_3^{\text{Li}^+} & \quad 6_3^{\text{Li}^+} \\
\text{protons} = 3 & \quad \text{protons} = 3 & \quad \text{protons} = 3 & \quad \text{protons} = 3 \\
\text{neutrons} = 4 & \quad \text{neutrons} = 3 & \quad \text{neutrons} = 4 & \quad \text{neutrons} = 3 \\
\text{electrons} = 3 & \quad \text{electrons} = 3 & \quad \text{electrons} = 2 & \quad \text{electrons} = 2
\end{align*}
\]

The **number of protons** never changes. This is why the **Atomic Number** for an element is defined as the **number of protons**.

<table>
<thead>
<tr>
<th>Element</th>
<th>Symbol</th>
<th>Atomic Number</th>
<th>Mass Number</th>
<th>number of protons</th>
<th>number of neutrons</th>
<th>number of electrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lithium</td>
<td>$^{7}_{3}^{\text{Li}^+}$</td>
<td>3</td>
<td>7</td>
<td>3</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Oxygen</td>
<td>$^{16}_{8}^{\text{O}^2-}$</td>
<td>8</td>
<td>16</td>
<td>8</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>Chlorine</td>
<td>$^{37}_{17}^{\text{Cl}^-}$</td>
<td>17</td>
<td>37</td>
<td>17</td>
<td>20</td>
<td>18</td>
</tr>
<tr>
<td>Sodium</td>
<td>$^{23}_{11}^{\text{Na}^+}$</td>
<td>11</td>
<td>23</td>
<td>11</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>$^{31}_{15}^{\text{P}^3-}$</td>
<td>15</td>
<td>31</td>
<td>15</td>
<td>16</td>
<td>18</td>
</tr>
<tr>
<td>Iron (II)</td>
<td>$^{56}_{26}^{\text{Fe}^{2+}}$</td>
<td>26</td>
<td>56</td>
<td>26</td>
<td>30</td>
<td>24</td>
</tr>
<tr>
<td>Iron (III)</td>
<td>$^{58}_{26}^{\text{Fe}^{3+}}$</td>
<td>26</td>
<td>58</td>
<td>26</td>
<td>32</td>
<td>23</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>$^{2}_{1}^{\text{H}^+}$</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Tin (II)</td>
<td>$^{116}_{50}^{\text{Sn}^{2+}}$</td>
<td>50</td>
<td>116</td>
<td>50</td>
<td>66</td>
<td>48</td>
</tr>
<tr>
<td>Tin (IV)</td>
<td>$^{119}_{50}^{\text{Sn}^{4+}}$</td>
<td>50</td>
<td>119</td>
<td>50</td>
<td>69</td>
<td>46</td>
</tr>
</tbody>
</table>
Q1. SC

The grid shows information about some particles.

<table>
<thead>
<tr>
<th>Particle</th>
<th>protons</th>
<th>neutrons</th>
<th>electrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>11</td>
<td>12</td>
<td>11</td>
</tr>
<tr>
<td>B</td>
<td>9</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>C</td>
<td>11</td>
<td>13</td>
<td>11</td>
</tr>
<tr>
<td>D</td>
<td>19</td>
<td>20</td>
<td>18</td>
</tr>
<tr>
<td>E</td>
<td>9</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

(a) Identify the particle which is a negative ion.
(b) Identify the two particles which are isotopes.

Q2. Int2

An atom has 26 protons, 26 electrons and 30 neutrons. The atom has:

A atomic number 26, mass number 56
B atomic number 26, mass number 52
C atomic number 30, mass number 56
D atomic number 30, mass number 82

Q3. Int2

Which line in the table describes a neutron?

<table>
<thead>
<tr>
<th>Mass</th>
<th>Charge</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>-1</td>
</tr>
<tr>
<td>B</td>
<td>0</td>
</tr>
<tr>
<td>C</td>
<td>+1</td>
</tr>
<tr>
<td>D</td>
<td>0</td>
</tr>
</tbody>
</table>

Q4. Int2

The isotopes of carbon and oxygen are given in the table.

**Isotopes of carbon**

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Mass</th>
<th>Charge</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{12}$C</td>
<td>6</td>
<td>-1</td>
</tr>
<tr>
<td>$^{13}$C</td>
<td>6</td>
<td>+1</td>
</tr>
<tr>
<td>$^{14}$C</td>
<td>6</td>
<td>0</td>
</tr>
</tbody>
</table>

**Isotopes of oxygen**

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Mass</th>
<th>Charge</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{16}$O</td>
<td>8</td>
<td>-2</td>
</tr>
<tr>
<td>$^{17}$O</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>$^{18}$O</td>
<td>8</td>
<td>0</td>
</tr>
</tbody>
</table>

A molecule of carbon dioxide with mass 46 could contain

A one $^{12}$C atom and two $^{16}$O atoms
B one $^{14}$C atom and two $^{18}$O atoms
C one $^{12}$C atom, one $^{16}$O atoms and one $^{18}$O atom
D one $^{14}$C atom, one $^{16}$O atoms and one $^{18}$O atom

Q5. Int2

In the manufacture of glass, other chemicals can be added to alter the properties of the glass. The element boron can be added to glass to make oven proof dishes.

Information about an atom of boron is given below.

<table>
<thead>
<tr>
<th>Particle</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>proton</td>
<td>5</td>
</tr>
<tr>
<td>electron</td>
<td>5</td>
</tr>
<tr>
<td>neutron</td>
<td>6</td>
</tr>
</tbody>
</table>

Use this information to complete the nuclide notation for this atom of boron.

B

Atoms of boron exist which have the same number of protons but a different number of neutrons from that shown in the table.

What name can be used to describe the different atoms of boron?

Q6. Int2

Elements are made up of atoms.

An atom of an element is represented by the diagram below.

A = protons
O = neutrons
O = electrons

What name is given to the part of the atom which contains protons and neutrons?

Using the information in the diagram:

(a) state the mass of this atom;

(b) explain why this atom is electrically neutral;

(c) name the family of elements to which this atom belongs.
2.2 Radioactivity

Stability

Most elements have *isotopes*, most of which are *unstable*.

Radioactivity is the result of *unstable nuclei* (radioisotopes) *rearranging* to form *more stable nuclei*.

*Energy* is always released and, often, a small *particle* is also *emitted* from the nucleus.

Emissions

Most radioactivity involves the *emission* of $\alpha$- and $\beta$-particles but *energy*, in the form of *high frequency electromagnetic radiation* is also released. These $\gamma$-rays are the same as other *electromagnetic radiation* such as radio-waves, visible light and x-rays but are of *higher energy* and, therefore, *more dangerous*.

<table>
<thead>
<tr>
<th>Type of emission</th>
<th>Property</th>
<th>$\alpha$-particle</th>
<th>$\beta$-particle</th>
<th>$\gamma$-rays</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>nature</em></td>
<td></td>
<td>2 protons, 2 neutrons</td>
<td>electron (n → p + e)</td>
<td>high frequency radiation</td>
</tr>
<tr>
<td><em>charge</em></td>
<td></td>
<td>2 +</td>
<td>1 -</td>
<td>0</td>
</tr>
<tr>
<td><em>mass</em></td>
<td></td>
<td>1 amu</td>
<td>0 amu</td>
<td>0</td>
</tr>
<tr>
<td><em>stopped by</em></td>
<td></td>
<td>paper</td>
<td>aluminium foil</td>
<td>lead sheet</td>
</tr>
<tr>
<td><em>electric field</em></td>
<td></td>
<td>slightly towards negative plate</td>
<td>greatly towards positive plate</td>
<td>no effect</td>
</tr>
</tbody>
</table>

KHS June 2017
All 3 types of **radiation** are capable of knocking **electrons** off any atoms they **collide** with so are sometimes referred to as **ionising radiation**.

The **ionising** effect of the **radiation** is used to both **detect** and **count** radiation - each particle entering the **detector** triggers an **electron** and the **flow of electrons** (current) determines the **amount**.

The **ionising** effect of the **radiation** can lead to **harmful** changes in **human tissue** - hence the protective clothing.

### Nuclear Equations

With the exception of $\gamma$-rays, all nuclear reactions involve particles with mass and charge so we can continue to write equations to represent these processes.

\[
\text{mass } \rightarrow 206^{\text{Pb}} \quad \text{charge } \rightarrow 82^{\text{Pb}}
\]

Most atoms continue to be represented by their usual **symbols** except that **mass numbers** are now **essential** and the ‘**atomic number**’ now represents the ‘**charge on the particle**’

---

For example:

\[
\begin{align*}
\text{an unstable polonium nucleus} & \quad \rightarrow \quad \text{a stable lead nucleus} \\
\text{an } & \quad \text{an } \\
210^{\text{Po}} & \quad 206^{\text{Pb}} \\
84 & \quad 82 \\
\end{align*}
\]

The main particles that **need to be learnt** are:-

\[
\begin{align*}
\alpha \quad \alpha - \text{particles} & \quad \text{(strictly speaking } ^4_2\text{He}^{2+}) \\
\beta \quad \beta - \text{particles} & \quad \text{(slow moving electrons emitted from the nucleus.)} \\
\text{neutrons} & \quad \text{protons}
\end{align*}
\]
As with all other equations, these must be balanced. This means that the overall mass on both sides must be the same and the overall charge on both sides must be the same.

\[ \begin{align*}
14_6^{\text{C}} & \rightarrow 14_7^{\text{N}} + 0_{-1}^{\text{e}} \\
\text{mass} &= 14 \\
\text{charge} &= 6+ 
\end{align*} \]

Typical processes include:-

**Alpha decay**

\[ \begin{align*}
230_{92}^{\text{U}} & \rightarrow 226_{90}^{\text{Th}} + 4_{2}^{\text{He}} \\
\text{Beta decay} & \rightarrow 216_{84}^{\text{Po}} + 216_{85}^{\text{At}} + 0_{-1}^{\text{e}} \\
\text{Gamma decay} & \rightarrow \text{this is the emission of energy so no equation possible} \\
\text{Nuclear Fusion} & \rightarrow \text{in suns, at temperatures of about 10 million K, small atoms can fuse together} \\
2_{1}^{\text{H}} + 3_{1}^{\text{H}} & \rightarrow + 1_{0}^{\text{n}} \\
\text{‘Man-made’ processes include:-} \\
\text{Nuclear Fission} & \rightarrow \text{in power stations atoms are bombarded with neutrons to form unstable nuclei which then split apart to form smaller atoms} \\
235_{92}^{\text{U}} + 1_{0}^{\text{n}} & \rightarrow 140_{54}^{\text{Xe}} + 235_{92}^{\text{U}} + 2_{0}^{\text{n}} \\
206_{84}^{\text{Po}} & \rightarrow 202_{82}^{\text{Pb}} + 4_{2}^{\text{He}} \\
124_{51}^{\text{Sb}} & \rightarrow 124_{52}^{\text{Te}} + 0_{-1}^{\text{e}} \\
129_{53}^{\text{I}} & \rightarrow 0_{-1}^{\text{e}} + 129_{54}^{\text{Xe}} \\
216_{86}^{\text{Rn}} & \rightarrow 4_{2}^{\text{He}} + 212_{84}^{\text{Po}} \\
235_{95}^{\text{Am}} & \rightarrow 4_{2}^{\text{He}} + 239_{97}^{\text{Bk}} \\
52_{22}^{\text{Ti}} & \rightarrow 0_{-1}^{\text{e}} + 52_{23}^{\text{V}} \\
257_{101}^{\text{Md}} & \rightarrow 4_{2}^{\text{He}} + 4_{2}^{\text{He}} + 249_{97}^{\text{Bk}} \\
255_{104}^{\text{Rf}} & \rightarrow 4_{2}^{\text{He}} + 251_{102}^{\text{No}} \\
85_{35}^{\text{Br}} & \rightarrow 0_{-1}^{\text{e}} + 85_{36}^{\text{Kr}} + 0_{0}^{\text{e}} \\
32_{15}^{\text{P}} & \rightarrow 0_{-1}^{\text{e}} + 32_{16}^{\text{S}} + 0_{0}^{\text{e}} \\
\end{align*} \]
Q1.
Phosphorus-32 and strontium-89 are two radioisotopes used to study how far mosquitoes travel. Strontium-89 decays by emission of a beta particle. Complete the nuclear equation for the decay of strontium-89.

\[ ^{89}\text{Sr} \rightarrow \]

Q2.
Alpha, beta and gamma radiation is passed from a source through an electric field onto a photographic plate.

Which of the following patterns will be produced on the photographic plate?

A  
\[ \text{top} \bullet \bullet \bullet \]
\[ \text{bottom} \]

B  
\[ \text{top} \bullet \bullet \bullet \]
\[ \text{bottom} \]

C  
\[ \text{top} \bullet \bullet \bullet \]
\[ \text{bottom} \]

D  
\[ \text{top} \bullet \bullet \bullet \]
\[ \text{bottom} \]

Q3.
From which of the following could \( ^{32}_{15}\text{P} \) be produced by neutron capture?

A  
\( ^{33}_{15}\text{P} \)

B  
\( ^{32}_{16}\text{S} \)

C  
\( ^{31}_{15}\text{P} \)

D  
\( ^{31}_{16}\text{S} \)

Q4.
Carbon-13 NMR is a technique used in chemistry to determine the structure of organic compounds. Calculate the neutron to proton ratio in an atom of carbon-13.

Q5.
Which particle will be formed when an atom of \( ^{211}_{83}\text{Bi} \) emits an \( \alpha \)-particle and the decay product then emits a \( \beta \)-particle?

A  
\( ^{207}_{82}\text{Pb} \)

B  
\( ^{208}_{84}\text{Tl} \)

C  
\( ^{209}_{80}\text{Hg} \)

D  
\( ^{210}_{79}\text{Au} \)

Q6.
The element iodine has only one isotope that is stable. Several of the radioactive isotopes of iodine have medical uses. Iodine-131, for example, is used in the study of the thyroid gland and it decays by beta emission. 

a) why are some atoms unstable?

b) complete the balanced nuclear equation for the beta decay of iodine-131.

\[ ^{131}_{53}\text{I} \rightarrow \]

Q7.
Thorium-227 decays by alpha emission.

a) Complete the nuclear equation for the decay of thorium-227.

\[ ^{227}\text{Th} \rightarrow \]

b) A sample of thorium-227 was placed in a wooden box. A radiation detector was held 10 cm away from the box. Why was alpha radiation not detected?

Q8.
An atom of \( ^{227}\text{Th} \) decays by a series of alpha emissions to form an atom of \( ^{211}\text{Pb} \). How many alpha particles are released in the process?
Radioactive Decay

The breakdown of the nuclei of unstable atoms is known as decay.

It is a totally random process, i.e. it is impossible to predict exactly when a particular nucleus will break apart.

It is also a purely nuclear reaction, i.e. it is not affected by most of the factors that affect normal chemical reactions such as:-

- **state**: solid, liquid, gas, solution, lump, powder etc. makes no difference
- **temperature**: do not decay faster when hot
- **form**: atoms, ions, single or in molecules makes no difference
- **pressure**: has no effect
- **catalysts**: have no effect

Though random, the decay will still follow a predictable pattern.

Starting with 100g of radioactive material, a geiger counter could detect 250 particles being emitted every minute.

The mass of radioactive material decreases, as does the activity.

The decrease is not constant, (i.e. not a straight line), but it does follow a pattern.

After a certain time the mass of radioactive material will fall to half its original value. The activity will also be halved. It will then take the same length of time for the mass, and the activity, to half again. This time is known as the half-life \( t_{\frac{1}{2}} \). In the example above, the half-life, \( t_{\frac{1}{2}} = 7 \) minutes.
Starting with a different mass, 80g, of radioactive material, a geiger counter would detect a lower activity, only 200 particles being emitted every minute.

However the half-life remains at 7 minutes.

The pattern for the decay remains the same regardless of the mass you start with.

Different isotopes decay at different rates but all show this pattern:

- some have a very short half-life e.g. $^{220}$Ra $t_{1/2} = 55$ seconds
- others have a very long half-life e.g. $^{238}$U $t_{1/2} = 4.51 \times 10^9$ years

<table>
<thead>
<tr>
<th>Radioisotope</th>
<th>Symbol</th>
<th>Radiation</th>
<th>Half-Life</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tritium</td>
<td>$^3$H</td>
<td>$\beta^-$</td>
<td>12.33 years</td>
<td>Biochemical tracer</td>
</tr>
<tr>
<td>Carbon-14</td>
<td>$^{14}$C</td>
<td>$\beta^-$</td>
<td>5730 years</td>
<td>Archaeological dating</td>
</tr>
<tr>
<td>Phosphorus-32</td>
<td>$^{32}$P</td>
<td>$\beta^-$</td>
<td>14.26 days</td>
<td>Leukemia therapy</td>
</tr>
<tr>
<td>Potassium-40</td>
<td>$^{40}$K</td>
<td>$\beta^-$</td>
<td>$1.28 \times 10^9$ years</td>
<td>Geological dating</td>
</tr>
<tr>
<td>Cobalt-60</td>
<td>$^{60}$Co</td>
<td>$\beta^-, \gamma$</td>
<td>5.27 years</td>
<td>Cancer therapy</td>
</tr>
<tr>
<td>Technetium-99m$^*$</td>
<td>$^{99m}$Tc</td>
<td>$\gamma$</td>
<td>6.01 hours</td>
<td>Brain scans</td>
</tr>
<tr>
<td>Iodine-123</td>
<td>$^{123}$I</td>
<td>$\gamma$</td>
<td>13.27 hours</td>
<td>Thyroid therapy</td>
</tr>
<tr>
<td>Uranium-235</td>
<td>$^{235}$U</td>
<td>$\alpha, \gamma$</td>
<td>$7.04 \times 10^8$ years</td>
<td>Nuclear reactors</td>
</tr>
</tbody>
</table>

*The $m$ in technetium-99m stands for metastable, meaning that it undergoes $\gamma$ emission but does not change its mass number or atomic number.

We consider that an isotope is ‘safe’ when the level of its activity falls to the level of normal background radiation.

Generally it takes about 6 to 8 half-lives.

We are all exposed to radiation all the time. About 85% of this is natural due to radioisotopes in rocks and radiation from the sun.

About 15% is man-made resulting from medical uses and, more controversially, from leakages from nuclear power stations and the disposal of nuclear waste.
Using Radioisotopes

There are very many uses for radioisotopes, these are a few.

Medical examining body tissues or organs

- e.g. \(^{132}\)I and \(^{125}\)I are used to test the health of the thyroid gland
  
  emits \(\gamma\)-radiation - high penetration - escapes body to be detected
  \(t_{1/2} = 13.27\) hrs - short half-life - become safe within days

  cancer treatments
  
  - e.g. \(^{60}\)Co is a powerful \(\gamma\)-emitter used to treat deep-seated tumours
    
    emits \(\gamma\)-radiation - high penetration - enters body to reach tumours
    \(t_{1/2} = 5.27\) yrs - medium half-life - machine emits constant level

  - e.g. \(^{32}\)P is a weak \(\beta\)-emitter which can be applied directly to treat skin cancer
    
    emits \(\beta\)-radiation - medium penetration - only has to go 'skin deep'
    \(t_{1/2} = 14.26\) days - short half-life - become safe within months

  - e.g. wires of \(^{198}\)Au can be placed inside tumours to dose them with radiation whilst minimising damage to surrounding healthy cells.
    
    emits \(\beta\)-radiation - medium penetration - won't escape from tumour
    \(t_{1/2} = 2.7\) days - short half-life - become safe within weeks

Industrial detecting flaws

- e.g. \(^{60}\)Co can be used to take ‘X-ray pictures’ of welds and castings

  measuring engine wear
  
  - e.g. engine/oil makers used piston rings with a thin layer of radioactive material on the surface to monitor wear without dismantling the engine

  detecting cracks in jet engines
  
  - e.g. \(\gamma\)-radiation from \(^{192}\)Ir is used to detect cracks in jet turbines

  domestic smoke detectors
  
  - e.g. \(^{241}\)Am emits \(\alpha\)-particles that even a small amount of smoke blocks
    
    emits \(\alpha\)-radiation - short penetration - won't escape from detector
    \(t_{1/2} = 432\) yrs - medium half-life - level of radiation won't drop in lifetime of detector.

small quantity minimises disposal problem.
measuring thickness/checking contents

e.g. the thickness of **steel** sheet or the level of **beer** in a can can be monitored.

**Scientific reaction pathways - using isotopic labelling**

e.g. \(^{18}\text{O}\) was used to determine the mechanism of the *esterification* reaction.

predicted mechanism

实际机制

radioactive \(^{18}\text{O}\) should have been part of the \(\text{H}_2\text{O}\) molecule formed in fact, \(^{18}\text{O}\) remained as part of the ester molecule.

e.g. \(^{32}\text{P}\) was used to follow the route taken through plants by **phosphorous**

\[ \text{ADP} \rightarrow \text{ATP} \]

dating

e.g. \(^{14}\text{C}\) is produced naturally in the upper **atmosphere**. While alive, **plants** and **animals** have a constant ratio of \(^{12}\text{C} : ^{14}\text{C}\). Once they die the \(^{14}\text{C}\) **decays**.

The half-life for \(^{14}\text{C}\) is about 5,730 years so the age of any object made from a living organism can be **estimated** by comparing it with a similar object today.
Both the fusion (smashing together) and the fission (splitting apart) of atoms provide potential for generating large amounts of energy.

**Nuclear Fission**

One of the possible reactions that could take place in a nuclear power station is:

\[
^1_0 n + ^{235}_{92} U \rightarrow ^{140}_{54} Xe + ^{23}_{92} U + 2 ^1_0 n
\]

A slow moving neutron is captured by a Uranium atom which then splits apart to produce two smaller ‘daughter’ atoms. The two neutrons produced can then go on to react with other Uranium atoms leading to a chain reaction.

A mole of Uranium, 235 g, yields as much energy as 60 tonnes of high quality coal which would also release 220 tonnes of CO\(_2\) into the atmosphere. Nuclear power stations could replace conventional fossil fuel power stations but....

<table>
<thead>
<tr>
<th><strong>Advantages</strong></th>
<th><strong>Diadvantages</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>no ‘greenhouse’ gases emitted</td>
<td>possibility of disastrous accident</td>
</tr>
<tr>
<td>no SO(_2) to add to ‘acid rain’</td>
<td>increase in ‘background’ radiation</td>
</tr>
<tr>
<td>safer mining uranium than mining coal</td>
<td>problems storing long term waste</td>
</tr>
<tr>
<td>uranium reserves will last longer than fossil fuel reserves</td>
<td>slow to change output levels to respond to peaks of demand</td>
</tr>
<tr>
<td>less visual impact than coal- or oil-fired power stations or wind farms etc</td>
<td>plutonium produced may lead to increase in nuclear weapons</td>
</tr>
<tr>
<td>fewer stations needed</td>
<td>much more expensive to build</td>
</tr>
<tr>
<td></td>
<td>more expensive to decommission</td>
</tr>
</tbody>
</table>

**Nuclear Fusion**

This is many peoples hope for the future. The main raw material would be hydrogen atoms extracted from water and it would produce no dangerous (long t\(_{1/2}\)) radioactive products. It would replicate one of the main reaction that powers a star.

\[
^2_1 H + ^3_1 H \rightarrow ^4_2 He + ^1_0 n
\]
Q1.

\[ ^2_1\text{H} + ^3_1\text{H} \rightarrow ^4_2\text{He} + ^0_1\text{n} \]

The above process represents

A) nuclear fusion
B) nuclear fission
C) neutron capture
D) proton capture

Q2.

Amercuric-241, a radioisotope used in smoke detectors, has a half-life of 432 years.

a) The equation for the decay of americum-241 is

\[ ^{241}_{95}\text{Am} \rightarrow ^4_2\text{He} + X \]

Name element X.

b) Name the type of radiation emitted by the americum-241 radioisotope.

c) Another radioisotope of americium exists which has an atomic mass of 242.

Americium-242 has a half-life of 16 hours.

A sample of americum-242 has a mass of 8 g. Calculate the mass, in grams, of americium-242 that would be left after 48 hours.

_______ g

Q3.

Phosphorus-32 and strontium-89 are two radioisotopes used to study how far mosquitoes travel.

In an experiment, 10 g of strontium-89 chloride was added to a sugar solution used to feed mosquitoes.

a) The strontium-89 chloride solution was fed to the mosquitoes in a laboratory at 20 °C. When the mosquitoes were released, the outdoor temperature was found to be 35 °C.

What effect would the increase in temperature have on the half-life of the strontium-89?

b) A mosquito fed on a solution containing phosphorus-32 is released. Phosphorus-32 has a half-life of 14 days.

When the mosquito is recaptured 28 days later, what fraction of the phosphorus-32 will remain?

Q4.

The graph shows how the mass of iodine-131 in a sample changes over a period of time.

What is the half-life of this isotope?

Q5.

Positron emission tomography, PET, is a technique that provides information about biochemical processes in the body.

Carbon-11, \(^{11}\text{C}\), is a positron-emitting radioisotope that is injected into the bloodstream.

A positron can be represented as \(^0_1\text{e}^+\)

a) Complete the nuclear equation for the decay of \(^{11}\text{C}\) by positron-emission.

\[ ^{11}\text{C} \rightarrow \]

b) A sample of \(^{11}\text{C}\) had an initial count rate of 640 counts min\(^{-1}\). After 1 hour the count rate had fallen to 80 counts min\(^{-1}\).

Calculate the half-life, in minutes, of \(^{11}\text{C}\).

__________ minutes

A sample of \(^{11}\text{C}\) is injected into the bloodstream as glucose molecules (\(\text{C}_6\text{H}_{12}\text{O}_6\)). Some of the carbon atoms in these glucose molecules are \(^{11}\text{C}\) atoms.

The intensity of radiation in a sample of \(^{11}\text{C}\) is compared with the intensity of radiation in a sample of glucose containing \(^{11}\text{C}\) atoms. Both samples have the same mass.

Which sample has the higher intensity of radiation?

Give a reason for your answer.
2.4 Electron Arrangement

Electron Shells

**Charge** - *electrons* are *charged* particles. They carry one unit of *negative* charge.

**Position** - they are found in the *space* around the *nucleus* in regions called *orbitals*.

**Mass** - they are extremely *small and light*. (About 1/2000th as heavy as a *proton*).

Some of the *electrons* are found quite close to the *nucleus* in what we call the *First Shell*. These electrons have *least energy*.

There is only room for 2 electrons in the *First Shell*, (the repulsive forces between the *electrons* are too strong to allow any more).

The next group of electrons are found *further* out from the nucleus in what we call the *Second Shell*. These electrons have *more energy*.

There is room for 8 electrons in this shell. There are 4 possible paths (*orbitals*) that the electrons can follow.

Each *orbital* is able to hold 2 electrons, but they will not ‘pair up’ until there are no more *empty* orbitals available. i.e. after 4 electrons.

The *Third Shell* is even *further out* from the nucleus. These electrons have even *more energy*.

Again, there are 4 *orbitals* and room for 8 electrons in total. We write this *electron arrangement* as:-

\[ 2, 8, 8 \]
Each new row (Period) in the Periodic Table represents the start of a new shell. As you move from left to right the shell is being filled, and the elements change from metals to non-metals.

The Alkali metals all have 1 electron in their outer shell. The Halogens all have 7, while the Noble gases all have a full outer shell. Elements which are in the same Group will have the same number of electrons in their outer shell and will have very similar properties.
When atoms get involved in reactions they have to physically touch, (collide with), each other. This really only affects the electrons in the outer shell. Not surprisingly then, the number of electrons an atom has in its outer shell is all important.

There are various methods for learning Formula Writing but most involve some idea of Bonding Power (Valency Number) which is determined by the number of electrons in the outer shell.
Only *unpaired electrons* in the *outer shell* of an atom can get involved in reactions, and form *bonds* with other atoms.

The *Noble gases* are very *unreactive* because they have no *unpaired electrons*.

One of the *driving forces* behind *bonding* will be the *advantages* that can be gained by achieving a *stable electron arrangement*, like the *Noble gases*. The 'easiest' way of doing this is to either:

- lose electrons from the outer shell
- gain electrons into the outer shell

*Metal* atoms tend to form *positive ions* by *giving away* their *outermost electrons* to achieve the *same electron arrangement* as the nearest *noble gas*.

*Non-metal* atoms tend to form *negative ions* by *gaining* extra *outermost electrons* to achieve the *same electron arrangement* as the nearest *noble gas*.

![Diagram showing electron arrangements and ion forms](image)

The *size of the charge* on an *ion* depends on the *number of electrons* given away or gained.

The *charge number* on an *ion* is the same as its *valency number*.
Q1. Int2

Which of the following numbers is the same for lithium and oxygen atoms?

A Mass number
B Atomic number
C Number of outer electrons
D Number of occupied energy levels

Q2. Int2

Elements are made up of atoms.

An atom of an element is represented by the diagram below:

- = protons
- = neutrons
- = electrons

a) explain why this atom is electrically neutral

b) name the family of elements to which this atom belongs.

Q3. SC

Identify the two elements which can form ions with the same electron arrangement as argon.

A oxygen
B potassium
C phosphorus
D aluminium
E fluorine
F bromine

Q4. SC

Identify the particle which has the same electron arrangement as neon.

A \( ^{23}_{11}\text{Na} \)
B \( ^{18}_{8}\text{O} \)
C \( ^{40}_{19}\text{K}^+ \)
D \( ^{24}_{12}\text{Mg}^{2+} \)
E \( ^{35}_{17}\text{Cl}^- \)
F \( ^{16}_{8}\text{O} \)

Q5. SG

Identify the two elements which have similar chemical properties

A gold
B magnesium
C carbon
D nitrogen
E calcium
F iodine

Q6. Int2

Atoms contain particles called protons, neutrons and electrons. Electrons are arranged in energy levels.

The nuclide notation of the sodium atom is shown.

\( ^{24}_{11}\text{Na} \)

a) complete the diagram to show how the electrons are arranged in a sodium atom.

b) explain what holds the negatively charged electrons in place around the nucleus.

Q7. Int2

Atoms of an element form ions with a single positive charge and an electron arrangement of 2, 8.

The element is

A fluorne
B lithium
C sodium
D neon

Q8. SG

Identify the symbol for the element which has similar chemical properties to oxygen.

The element is

A Mg
B N
C S
D F
Learning Outcomes Section 1

Knowledge Met in this Section

Atoms

• Every element is made up of small particles called atoms.
• Atoms of different elements are different.
• Atoms of different elements are given a different number called the atomic number.
• The atoms of different elements differ in size and mass.

Atomic structure

• All atoms have an extremely small positively charged central part called the nucleus.
• Negatively charged particles, called electrons, move around outside the nucleus.
• All atoms are electrically neutral because the positive charge of the nucleus is equal to the negative charges of all the electrons added together.

Protons, Neutrons, Mass numbers, etc.

• The nucleus of every atom is positively charged due to the presence of protons.
• The atoms of different elements have different numbers of protons.
• Almost all atoms have neutrons, which have no charge, in their nucleus.
• Protons and neutrons are much heavier than electrons.

<table>
<thead>
<tr>
<th>particle</th>
<th>charge</th>
<th>mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>proton</td>
<td>+1</td>
<td>1</td>
</tr>
<tr>
<td>neutron</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>electron</td>
<td>—1</td>
<td>0</td>
</tr>
</tbody>
</table>

• The number of protons in the atoms of a particular element is fixed.
• The number of neutrons in the atoms of an element can vary.
• Most elements are made up of more than one kind of atom.
• The atomic number of an atom is the number of protons in its nucleus.
• The mass number of an atom is the total number of protons and neutrons in its nucleus.
• Isotopes are atoms of the same element that have different numbers of neutrons. They have the same atomic number but different mass numbers.
• For any *isotope*, a special symbol, using *nuclide notation*, can be written to show its mass number and atomic number, e.g.:

\[
\begin{align*}
\text{mass number} & \rightarrow 7 \\
\text{atomic number} & \rightarrow 3
\end{align*}
\]

• *Nuclide notation* can also be used to represent *ions* - atoms which have *gained* or *lost* some of their *electrons* and become *charged* e.g.

\[
\begin{align*}
\text{charge on ion} & \rightarrow \text{charge on ion} \\
\text{1 electron} & \text{gained} \\
\text{2 electrons} & \text{lost}
\end{align*}
\]

**Relative Atomic Mass (RAM)**

• The relative atomic mass of an element is the *average of the mass numbers* of its isotopes, taking into account the *proportions of each*.
• The relative atomic mass of an element is rarely a whole number.
• The relative atomic mass of an element can be calculated using information from a *Mass Spectrometer*.

\[
\text{RAM} = \frac{(\text{mass}_1 \times \%_1) + (\text{mass}_2 \times \%_2) + \ldots}{100}
\]

**Stability**

• Radioactive decay involves changes in the *nuclei* of atoms
• Unstable nuclei (*radioisotopes*) are transformed into more stable nuclei by the *emission* of small particles and the *release of energy*.
• The stability of nuclei depend on the *neutron: proton ratio* which can be calculated as

\[
\text{neutrons} / \text{protons}
\]
• As you go through the Periodic Table larger numbers of neutrons are needed and the *neutron : proton ratio increases* from 1 to 1.5.
Emissions

- There are 3 main types of emissions referred to as **alpha (α) particles**, **beta (β) particles** and **gamma (γ) rays**

- **alpha (α) particles** -
  - **nature** - like a helium nucleus
  - **symbol** - $^4_2\text{He}^{2+}$
  - **mass** - 4
  - **charge** - positively charged
  - **deflection** - towards negative plate
  - **penetration** - low

- **beta (β) particles** -
  - **nature** - high energy electron
  - **symbol** - $^0_{-1}\text{e}$
  - **mass** - 0
  - **charge** - negatively charged
  - **deflection** - towards positive plate
  - **penetration** - medium

- **gamma (γ) rays** -
  - **nature** - electromagnetic radiation
  - **symbol** - $\gamma$
  - **mass** - 0
  - **charge** - 0
  - **deflection** - not deflected
  - **penetration** - high

Nuclear Equations

- **Balanced** nuclear equations can be written involving:
  - neutrons - $^1_0\text{n}$
  - protons - $^1_1\text{p}$
  - α particles - $^4_2\text{He}$
  - β particles - $^0_{-1}\text{e}$

- During nuclear reactions:
  - overall **mass** is conserved
  - overall **charge in nuclei** is conserved
Radioactive Decay

- The decay of individual nuclei within a sample is random and is independent of chemical or physical state.
- Nuclear chemistry is not affected by the same factors as ‘normal’ (electron) chemistry such as: temperature, concentration, particle size, atom or ion, physical state, etc.
- The half-life is the time taken for the activity or mass of a radioisotope to halve.
- Given the values of two of these variables, the value of the other can be calculated:
  
  \[
  \text{quantity of radioisotope}, \\
  \text{half-life}, \\
  \text{time elapsed}.
  \]

Using Radioisotopes

- Radioisotopes are used in:
  
  \text{medicine} - tracers, cancer treatments, imaging etc
  \text{industry} - tracers, measuring, imaging, energy etc
  \text{science} - tracers, measuring, imaging, dating etc

- Radioisotopes with long half-lives give 'constant' readings over large time periods but can require expensive arrangements for disposal / storage.
- Radioisotopes with short half-lives should decay to 'safe' levels quickly.
- Radioisotopes with low penetration are easier to shield and can be used within a person with little risk of exposure for people coming into contact.
- Radioisotopes with high penetration are useful for imaging and treatments from outside the body, but have to be carefully screened.

Nuclear Energy

- Nuclear fission involves creating unstable nuclei by neutron bombardment which then 'split' to produce smaller 'daughter' nuclei
- During nuclear fission, neutrons are produced which can lead to a chain reaction and, if not controlled, a nuclear explosion or meltdown.
- Nuclear fuels and fossil fuels can be compared in terms of safety, pollution and use of finite resources.
- Elements are created in the stars from simple elements by nuclear fusion.
- All naturally occurring elements, including those found in our bodies, originated in the stars.
- Nuclear fusion has the potential to be a safe, non-polluting source of energy but there are enormous engineering problems to be overcome.
Electron Shells

- Electrons are arranged in special layers (called shells) around each nucleus. **Electron arrangements** are given in the data booklet.
- **Electron arrangements** for the first 20 elements in the Periodic Table can be worked out on the basis of

  - **first shell** - maximum 2 electrons
  - **second shell** - maximum 8 electrons
  - **third shell** - maximum 8 electrons

- Larger shells are divided into regions called **orbitals** which can each hold a **pair** of electrons
- Each orbital in a shell must have one electron before any **pairing** of electrons takes place

Electrons & The Periodic Table

- Each row (**Period**) represents a new shell, and the shell is gradually filled as we move across the **period**.
- As we move across the period, **properties gradually change** from 'typically metallic' to 'typically non-metallic'.
- Elements in the same column (**Group**) have the **same number of outer electrons** and have **similar chemical properties**.

Electrons & Bonding

- The **number of outer electrons** determines the **bonding power** of an atom.
- Atoms can become more stable by **losing** or **gaining electrons** to form **ions**.
- The **number of outer electrons** determines the **charge on the ion** most likely to be formed from a particular atom.
CONSOLIDATION QUESTIONS

Q1. Int2/H

Atoms and ions contain particles called protons, neutrons and electrons.

The nuclide notation of a phosphide ion is shown.

\[ ^{32}_{15}P^{3-} \]

a) Complete the table to show the number of each type of particle in this phosphide ion.

<table>
<thead>
<tr>
<th>Particle</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>electron</td>
<td></td>
</tr>
<tr>
<td>proton</td>
<td></td>
</tr>
<tr>
<td>neutron</td>
<td></td>
</tr>
</tbody>
</table>

b) Phosphorus-32 decays by beta-emission. Write the nuclear equation for the decay of phosphorus-32.

Q2. Int2

The table shows information about an ion.

<table>
<thead>
<tr>
<th>Particle</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>protons</td>
<td>16</td>
</tr>
<tr>
<td>neutrons</td>
<td>17</td>
</tr>
<tr>
<td>electrons</td>
<td>18</td>
</tr>
</tbody>
</table>

The charge on the ion is

A - 2
B - 1
C + 1
D + 2

Q3. Int2

Which of the following particles contains a different number of electrons from the others?

A Cl^- 
B O^2- 
C Ne 
D Na^+ 

Q4. Int2

The alkali metals, the halogens and the noble gases are the names of groups of elements in the Periodic Table.

Complete the table by circling a word in each box to give correct information about each group.

(Two pieces of correct information have already been circled.)

<table>
<thead>
<tr>
<th>Group</th>
<th>Metals</th>
<th>Non-metals</th>
<th>Reactive / Non-reactive</th>
</tr>
</thead>
<tbody>
<tr>
<td>alkali metals</td>
<td>metals</td>
<td>non-metals</td>
<td>reactive / non-reactive</td>
</tr>
<tr>
<td>halogens</td>
<td>metals</td>
<td>non-metals</td>
<td>reactive / non-reactive</td>
</tr>
<tr>
<td>noble gases</td>
<td>metals</td>
<td>non-metals</td>
<td>reactive / non-reactive</td>
</tr>
</tbody>
</table>

Complete the table for the particle shown below.

\[ ^{11}_{24}Na^+ \]

Key:
- p = proton
- n = neutron
- e = electron

<table>
<thead>
<tr>
<th>Atomic number</th>
<th>Symbol for the element</th>
<th>Mass number</th>
<th>Overall charge of the particle</th>
</tr>
</thead>
</table>

Q5. Int2

Atoms and ions contain particles called protons, neutrons and electrons.

The nuclide notation of a sodium ion is shown.

\[ ^{24}_{11}Na^+ \]

a) What is the difference between an atom and an ion?

b) Complete the table to show the number of each type of particle in this sodium ion.

<table>
<thead>
<tr>
<th>Particle</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>electron</td>
<td></td>
</tr>
<tr>
<td>proton</td>
<td></td>
</tr>
<tr>
<td>neutron</td>
<td></td>
</tr>
</tbody>
</table>
**CONSOLIDATION QUESTIONS**

**Q1.** When an atom $X$ of an element in Group 1 reacts to become $X^2^+$, which of the following represents the correct statement?

A. The mass number of $X$ decreases
B. The atomic number of $X$ increases
C. The charge of the nucleus increases
D. The number of occupied energy levels decreases

**Q2.** Some smoke detectors make use of radiation which is very easily stopped by tiny smoke particles moving between the radioactive source and the detector.

The most suitable type of radioisotope for a smoke detector would be

A. An alpha-emitter with a long half-life
B. A gamma-emitter with a short half-life
C. An alpha-emitter with a short half-life
D. A gamma-emitter with a long half-life

**Q3.** Which particle will be formed when an atom of $^{234}_{90}$Th emits a $\beta$-particle?

A. $^{234}_{91}$Pa
B. $^{230}_{88}$Ra
C. $^{234}_{89}$Ac
D. $^{238}_{92}$U

**Q4.** $^{14}$C has a half-life of 5600 years. An analysis of charcoal from a wood fire shows that its $^{14}$C content is 25% of that in living wood. How many years have passed since the wood for the fire was cut?

A. 1400
B. 4200
C. 11200
D. 16800

**Q5.** In which of the following compounds do both ions have the same number of electrons as neon?

A. Calcium fluoride
B. Magnesium chloride
C. Sodium oxide
D. Aluminium bromide

**Q6.** The chart was obtained from a 24-day old sample of an $\alpha$-emitting radioisotope of Radon.

The chart below shows the abundance of different mass numbers.

<table>
<thead>
<tr>
<th>Mass Number</th>
<th>Abundance (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>198</td>
<td>100</td>
</tr>
<tr>
<td>220</td>
<td>80</td>
</tr>
<tr>
<td>222</td>
<td>20</td>
</tr>
</tbody>
</table>

**a)** What is the half-life of the isotope?

A. 2 days
B. 4 days
C. 8 days
D. 12 days

**b)** $^{222}_{86}$Rn $\rightarrow ^a_b X + ^4_2$He

Identify element X and the values of $a$ and $b$.

**c)** Radon-222 can be produced from another radioisotope after six $\alpha$-emissions and two $\beta$-emissions. Identify the starting radioisotope.
CONSOLIDATION QUESTIONS

Q1. Int2
Which of the following is the electron arrangement for an alkali metal?
(You may wish to use your Data Book to help)

A 2, 1  
B 2, 2  
C 2, 3  
D 2, 4

Q2. Int2
a) Complete each line below by providing the correct symbol and electron arrangement for each atom.
   (You may wish to use your Data Book to help)

   e.g. sodium atom  Na  2,8,1
        oxygen atom
        lithium atom
        chlorine atom
        sulphur atom
        magnesium atom
        nitrogen atom
        aluminium atom

b) Complete each line below by providing the correct symbol and electron arrangement for each ion.

   e.g. sodium ion  Na⁺  2,8
        oxygen atom
        lithium atom
        chlorine atom
        sulphur atom
        magnesium atom
        nitrogen atom
        aluminium atom

c) What do you notice about the electron arrangements of these ions?

Q3. Int2
The table shows the numbers of protons, electrons and neutrons in four particles, W, X, Y and Z.

<table>
<thead>
<tr>
<th>Particle</th>
<th>Protons</th>
<th>Electrons</th>
<th>Neutrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>W</td>
<td>17</td>
<td>17</td>
<td>18</td>
</tr>
<tr>
<td>X</td>
<td>11</td>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td>Y</td>
<td>17</td>
<td>17</td>
<td>20</td>
</tr>
<tr>
<td>Z</td>
<td>18</td>
<td>18</td>
<td>18</td>
</tr>
</tbody>
</table>

Which pair of particles are isotopes?

A  W and X  
B  W and Y  
C  X and Y  
D  Y and Z  

Q4. H
Give the symbol for each of these particles

   alpha particle
   beta particle
   neutron
   proton
   electron

Which two particles are the same?

Q5. H
Which of the following equations represents nuclear fusion?

A  \( ^{40}_{19}K + ^{0}_{-1}e \rightarrow ^{40}_{18}Ar \)
B  \( ^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n \)
C  \( ^{235}_{92}U + ^{1}_{0}n \rightarrow ^{90}_{38}Sr + ^{144}_{54}Xe + 2 ^{1}_{0}n \)
D  \( ^{14}_{7}N + ^{1}_{0}n \rightarrow ^{14}_{6}C + ^{1}_{1}p \)
The following graph was obtained for a sample of lithium.

a) How many isotopes are present in the sample of lithium?

b) Using the information in the graph, calculate the relative atomic mass of lithium.

c) If the relative atomic mass of lithium was 6.5 what would that suggest about the relative amounts of the two isotopes.

d) If the relative atomic mass of lithium was 6.80, calculate the % abundance of each isotope.

**Hint 1:**

Let $x = \text{ % abundance of } ^{6}\text{Li}$

Let $y = \text{ % abundance of } ^{7}\text{Li}$

**Hint 2:** In maths, you can solve two unknowns $(x \text{ and } y)$ if you have two equations that link $x$ and $y.$