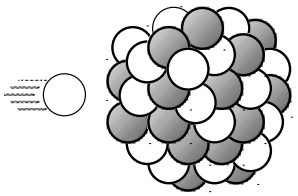


Higher Chemistry

Unit 3: Chemical Reactions

Redox, Nuclear Chemistry & Chemical Industry

Student:

Lesson	Activities			Done	Checked
3.1 ***Redox***	1.	Definitions			
	2.	Oxidising Agents & Reducing Agents			
	3.	Ion-Electron ½ equations			
		Check Test	Score: /		
		Home Practice	Score: /		
3.2 ***Electrolysis***	1.	Definitions			
	2.	The Faraday			
	3.	Calculations			
		Check Test	Score: /		
		Home Practice	Score: /		
3.3 ***Radioactivity***	1.	Stability			
	2.	Emissions			
	3.	Nuclear Equations			
		Check Test	Score: /		
		Home Practice	Score: /		
3.4 ***Nuclear Chemistry***	1.	Radioactive Decay			
	2.	Using Radioisotopes			
	3.	Nuclear Energy			
		Check Test	Score: /		
		Home Practice	Score: /		
3.5 ***Chemical Industry***	1.	Research & Development			
	2.	Building the Plant			
	3.	The Process			
		Check Test	Score: /		
		Home Practice	Score: /		
	1.				
	2.				
	3.				
		Check Test	Score: /		
		Home Practice	Score: /		
	1.				
	2.				
	3.				
		Check Test	Score: /		
		Home Practice	Score: /		
Consolidation Work		Consolidation A	Score: /		
		Consolidation B	Score: /		
		Consolidation C	Score: /		
		Consolidation D	Score: /		

End-of-Section Assessment	Score: %	Grade:	

Redox

1. *An **oxidising agent** is a substance which accepts electrons; a **reducing agent** is a substance which donates electrons*

2. *Oxidising and reducing agents can be identified in redox reactions*

3. ***Ion-electron equations** can be written for oxidation and reduction reactions.*

4. *Ion-electron equations can be combined to produce **redox** reactions*

5. *Given reactant and product species, ion-electron equations can be written which include H_2O and H^+.*

6. *The concentration of a reactant can be calculated from the results of **volumetric titrations***

7. *The production of one mole of an element from its ion, by electrolysis, always requires n times **96500 C** where n is the number of electrons in the relevant ion-electron equation*

8. *The **mass** or **volume** of an element discharged can be **calculated** from the quantity of electricity passed and **vice-versa**.*

Redox

Oxidising agents gain electrons - are reduced
Reducing agents lose electrons - are oxidised

Data Booklet contains most equations you will ever need

Balance electrons lost with electrons gained

e.g. $MnO_4^- \longrightarrow Mn^{2+}$

$MnO_4^- + 8H^+ + 5e \longrightarrow Mn^{2+} + 4H_2O$

$C_{red} \times V_{red} = \boxed{n_{red} \rightarrow \text{equation} \rightarrow n_{ox}} \rightarrow n_{ox} / V_{ox} = C_{ox}$
(***known***) (***known***)

or (if easier) $C_{red} \times V_{red} \times P_{red} \rightarrow C_{ox} \times V_{ox} \times P_{ox}$

P_{red} = number of e gained P_{ox} = number of e lost

e.g. $Al^{3+} + 3e \rightarrow Al$ $\quad 3F \rightarrow 1$ mole
$2H^+ + 2e \rightarrow H_2$ $\quad 2F \rightarrow 1$ mole

3 x 96500 = 288,500C 2 x 96,500 = 193,000 C

Current = I in ***amps*** Time = t in ***seconds***
Quantity of electricity = Q in ***coulombs***

$$\mathbf{Q = I \; x \; t}$$

$Al^{3+} + 3e \rightarrow Al$ $\quad 3F \rightarrow 1$ mole
$2H^+ + 2e \rightarrow H_2$ $\quad 2F \rightarrow 1$ mole

288,500C → 27g 193,000C → molar V (eg 24 *l*)

a value for molar Volume will be supplied in the question

3.1 Redox

Definitions

OIL RIG

Oxidation Is Loss of electrons by a reactant.

Gaining ***oxygen***/ losing ***hydrogen*** (*increasing* O:H ***ratio***) can also be described as ***Oxidation***:-

e.g. *aldehyde* (—CHO) → *acid* (—COOH)

e.g *alcohol* ($—CH_2OH$) → *aldehyde* (—CHO)

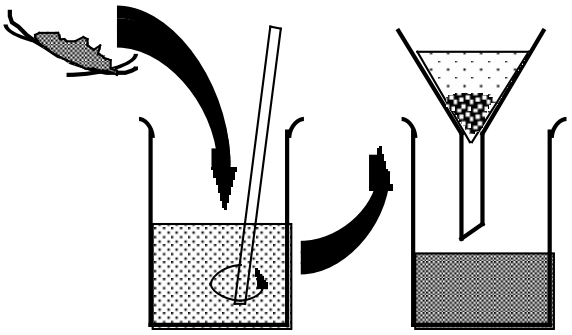
Reduction Is Gain of electrons by a reactant.

Losing ***oxygen***/gaining ***hydrogen*** (*decreasing* O:H ***ratio***) can also be described as ***Reduction***:-

e.g. *ketone* (—CO—) → *alcohol* (—CHOH—)

Oxidation and ***Reduction*** always go together so we call these reactions ***REDOX***.

The ***reactant*** which is ***oxidised*** is *causing the reduction* of the other reactant so it can often be referred to as the ***Reducing Agent***.



For example, during the ***displacement*** of *copper* by *zinc*, the following reactions occur.

Oxidation: $Zn_{(s)} \rightarrow Zn^{2+}_{(aq)} + 2e$

Reduction: $Zn^{2+}_{(aq)} + 2e \rightarrow Cu_{(s)}$

The ***zinc atoms*** are *causing the reduction* so the ***zinc atoms*** are the ***reducing agents***

Similarly, the ***reactant*** which is ***reduced*** is *causing the oxidation* of the other reactant so it can often be referred to as the ***Oxidising Agent***.

In the example above, the ***copper ions*** are *causing the oxidation* so the ***copper ions*** are the ***oxidising agents***.

During the Organic Unit you were asked to learn the following ***oxidation*** reactions:

primary alcohol → ***aldehyde*** → ***acids*** and ***secondary*** alcohol → ***ketone***

A number of ***oxidising agents*** can be used; each time the ***agent*** will itself be ***reduced***

e.g. ***acidified dichromate*** $Cr_2O_7^{2-} + 14H^+ + 6e \rightarrow 2Cr^{3+} + 7H_2O$

fehlings/benedicts $Cu^{2+} + e \rightarrow Cu^+$

tollens reagent $Ag^+ + e \rightarrow Ag$

Oxidising Agents & Reducing Agents

Help continues to be available in the Data Booklet in the form of the ***Electrochemical Series***.

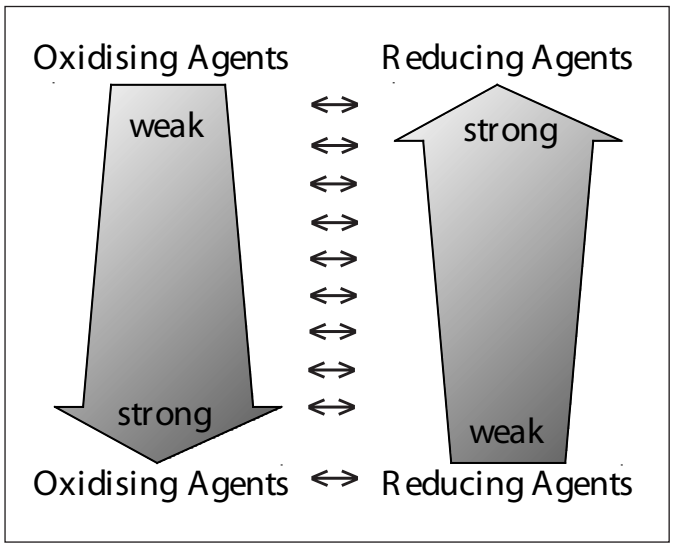
Equations are always written as ***Reduction*** reactions, but can be ***reversed*** for ***Oxidation*** reactions. Generally speaking, each equation represents the following change:

	Oxidising agent	***+***	***e***	***→***	***Reducing agent***
e.g.	K^+	+	e	→	K

This reaction, from near the ***top*** of the ***electrochemical series***, is *very unlikley* to go ***as written*** so we can describe ***potassium ions*** as ***very weak oxidising agents*** while ***potassium atoms*** would make ***very strong reducing agents***.

	Oxidising agent	***+***	***e***	***→***	***Reducing agent***
e.g.	$Cr_2O_7^{2-}$	+ $14H^+$ +	6e	→	$2Cr^{3+}$ + $7H_2O$

This reaction, from near the ***bottom*** of the ***electrochemical series***, is *very likely* to go ***as written*** so we can describe ***dichromate ions*** as ***very strong oxidising agents*** while ***chromium (III) ions*** would make ***very weak reducing agents***.



A useful *'rule-of-thumb'* that is worth remembering is that the

reaction lower in the series goes as written
while the
reaction further up will be reversed.

e.g a simple ***displacement***reaction, eg Zn/Cu

Cu^{2+} + 2e → Cu ***as written***

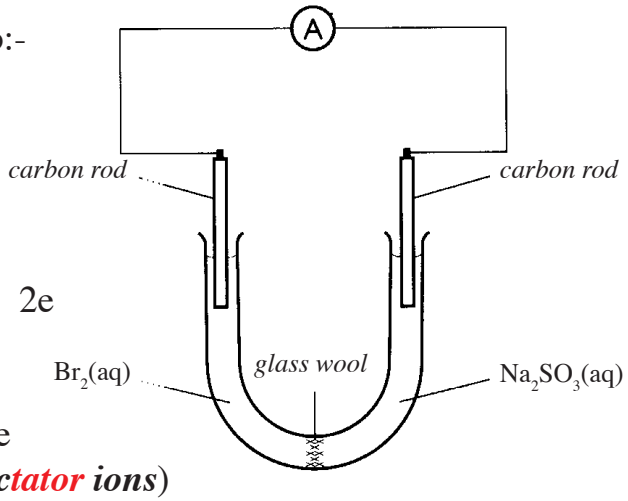
Zn → Zn^{2+} + 2e ***reversed***

In this example, ***bromine*** is ***lower*** in the series so:-

Br_2 + 2e → $2Br^-$

While ***sulphite ions*** are found ***higher*** in the series so:-

SO_3^{2-} + H_2O → SO_4^{2-} + $2H^+$ + 2e



(Sodium ions are so far up the series that it is safe to assume that they will never react; they are ***spectator ions***)

Ion-electron ½ equations

There are rules that can be used to ***balance*** ½ equations.

Many ***oxidation/reduction*** reactions need more than just ***electrons*** to keep them ***balanced***. A balanced equation (even a ½ equation) must have the *same number of each type of atom* on both sides and the *overall charge* on both sides *must be the same*.

e.g ***dichromate ions*** *(orange)* are strong ***oxidising agents*** because they are ***easily reduced*** to form ***chromium (III) ions*** *(green)*.

$Cr_2O_7^{2-} \rightarrow Cr^{3+}$ *(unbalanced)*

Step 1 there must be an *equal number of chromiums* on both sides so,

$Cr_2O_7^{2-} \rightarrow \mathbf{2}\ Cr^{3+}$

Step 2 there must be an *equal number of oxygens* on both sides so ***water is added***,

$Cr_2O_7^{2-} \rightarrow 2\ Cr^{3+} + \mathbf{7\ H_2O}$

Step 3 there must be an *equal number of hydrogens* on both sides so ***H^+ ions are added***,

$Cr_2O_7^{2-} + \mathbf{14\ H^+} \rightarrow 2\ Cr^{3+} + 7\ H_2O$

Step 4 there must be an *equal amount of charge* on both sides so ***electrons are added***,

(2— and 14 + = **12 +**) (2 times 3 + = **6+**)

$Cr_2O_7^{2-} + 14\ H^+ + \mathbf{6e} \rightarrow 2\ Cr^{3+} + 7\ H_2O$

(2— and 14 + and 6 — = **6 +**) (2 times 3 + = **6+**)

(Most ***redox*** reactions will only take place in ***solution***, so there will be plenty of H_2O and H^+ available when needed.The pH of a solution often ***changes*** during a Redox reaction. If a large number of H^+ ions are needed then ***acid*** may be added e.g. *'acidified dichromate'*.)

Ion-electron ½ equations can be used to write the overall equation for the ***Redox*** reaction.

For example, ***dichromate ions*** can be used to ***oxidise*** *iron(II) ions* to form *iron(III) ions*:-

$Fe^{2+} \rightarrow Fe^{3+} + e$

The ***number of electrons lost*** has to balance the ***number of electrons gained***. So:-

$6\ Fe^{2+} \rightarrow 6\ Fe^{3+} + 6e$

and $Cr_2O_7^{2-} + 14\ H^+ + 6e \rightarrow 2\ Cr^{3+} + 7\ H_2O$

To give the overall ***redox*** equation:-

$6\ Fe^{2+} + Cr_2O_7^{2-} + 14\ H^+ \rightarrow 6\ Fe^{3+} + 2\ Cr^{3+} + 7\ H_2O$

This in turn, supplies ***moles relationships*** that can be used to *calculate* ***concentrations*** from the results of ***Redox Titrations***

A Redox Titration

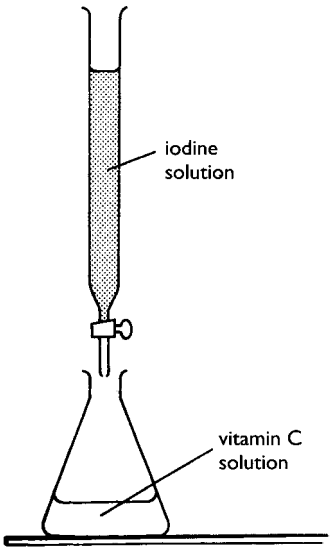
PPA

* *State the aim of the experiment*

* *using the molecular formula for vitamin C write equations for the oxidation and reduction half -reactions and hence write a balanced equation for the redox reaction between vitamin C and iodine.*

Procedure

* *Write a brief description of the experimental procedure you carried out to determine the mass of vitamin C in a tablet.*



Results

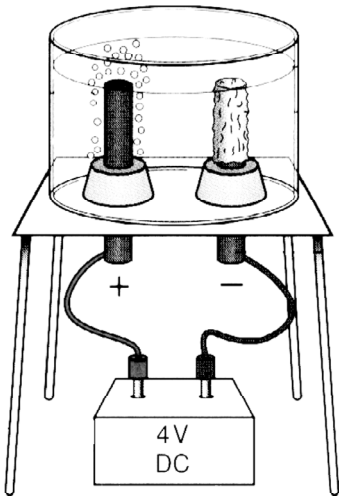
* *Present your results in an appropriate manner*

Calculation / Conclusion

* *Carry out a calculation to determine the mass of vitamin C in the tablet.*

3.2 Electrolysis

Definitions



Any ***liquid*** which contains ***ions*** is known as an ***electrolyte***. All ***ionic compounds*** are ***solids*** at room temperature so most ***electrolytes*** are ***solutions***.

When a ***current*** (DC) is passed through an ***electrolyte***, *chemical changes* occur usually resulting in the ***decomposition*** (*breaking apart*) of the ***compound***. This is called ***electrolysis***.

The apparatus used is called an ***electrolytic cell***.

If a ***melt*** is used, *non-metals* will form on the ***positive*** electrode (*anode*) while *metals* form on the ***negative*** electrode (*cathode*).

e.g $2Cl^- \rightarrow Cl_2 + 2e$ and $Cu^{2+} + 2e \rightarrow Cu$

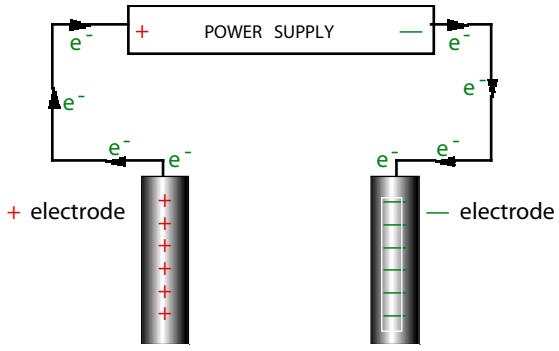
If a ***solution*** is used:- ***hydrogen*** *may* form at the ***negative*** electrode

$2H_2O + 2e \rightarrow H_2 + 2OH^-$ (data booklet)

oxygen *may* form at the ***positive*** electrode

$2H_2O \rightarrow O_2 + 4H^+ + 4e$ (data booklet)

The actual ***products of electrolysis*** wil depend on *how easy it is to make the ions react*, the *concentration* of the ions, the *voltage* being used and the *material used for the electrodes*.



$$I = Q \div t$$

or

$$Q = I \times t$$

An electric ***current*** is a flow of ***electrons***.

symbol = **I** *unit* = **Amps** (A or mA)

The size of a ***current*** tells you *how many* ***electrons*** pass through the ***ammeter*** *each* ***second***.

Each ***electron*** carries *one unit* of ***negative*** *charge*.

More accurately, the ***current*** tells you *how muc* ***charge*** is passing through the ***ammeter*** *per* ***second***.

symbol = **Q** *unit* = **Coulomb** (C)

i.e. a *current of 1 Amp* means that *1 Coulomb of negative charge* is passing through the meter in *1 Second*.

The *charge on 1 electron* = **1.60 x 10^{-19} C**. So, during ***electrolysis***, if we *measure* the ***current*** and the ***time*** we can *calculate* numbers of ***electrons*** passing through each *electrode* and then *numbers of ions* discharged/atoms formed at each *electrode*.

The Faraday

As usual, when it comes to *'counting'* small particles like ***electrons*** or ***atoms*** then we prefer to use ***molar*** quantities.

1 mole of electrons = 6.02 x 10^{23} *charge on electron* = 1.60 x 10^{-19} C (Data Book)

charge on 1 mole of electrons = (6.02 x 10^{23}) x (1.60 x 10^{-19}) C

charge on 1 mole of electrons = ***1 Faraday*** = ***1 F*** = **96,500 C** (Data Book)

If we know the ion-electron ½ equation we can quickly work out how much electricity is needed to discharge 1 mole exactly.

e.g.

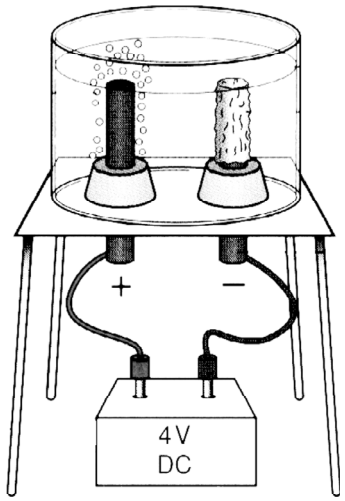
Na^+	+	e	→	Na	*requires*	**1** *Faraday* = 96,500 C
Mg^{2+}	+	2e	→	Mg	*requires*	**2** *Faradays* =193,000 C
Al^{3+}	+	3e	→	Al	*requires*	**3** *Faradays* =289,500 C
$2Cl^-$	→	Cl_2	+	2e	*requires*	**2** *Faradays* =193,000 C

Calculations

As usual, there will be variations, but most calculations will require

① *the **ion-electron** ½ **equation** for the reaction*

② *the **current** and the **time** for the electrolysis*



For example, *A solution of copper(II) chloride had a current of 0.5A passed through it for 10 minutes. calculate the mass of copper produced by this electrolysis.*

current, I = **0.5** A

time, t = 10 x 60 = **600** seconds

charge, Q = I x t = **0.5** x **600** = ***300*** C

Copper (II) chloride contains Cu^{2+} ions so, Cu^{2+} + 2e ⟶ Cu

2 moles ⟶ 1mole

2 moles of e = 2F = 2 x 96,500C — C ⟶ 1mole

1 mole of Cu = 63.5 g — C ⟶ 63.5 g

using proportion — ***300*** C ⟶ $\frac{300}{193{,}000}$ x 63.5 g

=> 0.0095 g

Quantitative Electrolysis

PPA

* *State the aim of the experiment*

Procedure

* *Draw a labelled diagramof the circuit*

* *List all the measurements that were made during the experiment*

Results

* *Present your results in an appropriate manner*

Calculation / Conclusion

* *Carry out a calculation to determine the quantity of electricity required to produce one mole of hydrogen. Assume the molar volume of hydrogen to be 24.1 litres mol^{-1}.*

In theory, 193 000 C are required to produce one mole of hydrogen by electrolysis.

* *Suggest sources of error which could account for any difference between your results and the theoretical one.*

Nuclear Chemistry

Nuclear Chemistry

1. *Radioactive decay involves changes in the* ***nuclei*** *of atoms*

2. *Unstable nuclei (**radioisotopes**) are transformed into more stable nuclei by releasing energy.*

3. *The stability of nuclei depend on the proton/ neutron ratio*

More protons (greater repulsion) in a nucleus the more neutrons are needed to stabilise the nucleus, so as you go through the Periodic Table the neutron: proton ratio increases. Even then, some combinations are unstable cnough to need to rearrange themselves (radioisotopes)

4. *The nature and properties of **alpha** (α), **beta** (β) and **gamma** (γ) radiation can be described*

α - particles, +ve, $^{4}_{2}He^{2+}$, low penetration
β - particles, -ve, e^{-}, medium penetration
γ - rays, no charge, high penetration

5. *Balanced nuclear equations, involving neutrons, protons, α and β particles can be written*

neutrons $^{1}_{0}n$, protons $^{1}_{1}p$, alpha $^{4}_{2}He$, beta $^{0}_{-1}e$

6. *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

$^{238}U_{(s)} = {}^{238}U_{(l)} = {}^{238}U_{(g)} = {}^{238}U_{(aq)} = {}^{238}U_{hot} = {}^{238}U_{cold}$

7. *The **half-life** is the time taken for the activity or mass of a radioisotope to halve*

8. *Given the values of two of these variables, the value of the other can be **calculated**:*

quantity of radioisotope, half-life, time elapsed.

9. *Radioisotopes are used in medicine, in industry, for scientific research including carbon dating and to produce energy.*

medicine - to include cancer treatments and use of ***tracers***
industry - to include measuring devices
energy production - to include ***uranium fission*** and ***nuclear fusion***

10. *Nuclear fuels and fossil fuels can be compared in terms of safetv, pollution and use of finite resources*

11. *Elements are created in the stars from simple elements by nuclear fusion*

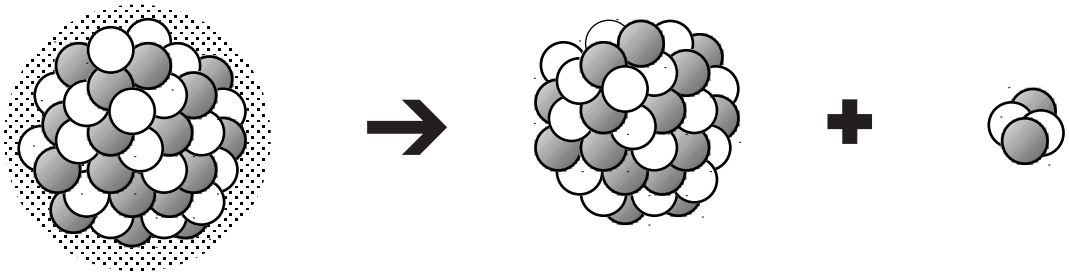
12. *All naturallv occuring elements, including those found in our bodies, originated in the stars*

3.3 Radioactivity

Stability

Radioactivity is the result of ***unstable nuclei*** *rearranging* to form ***stable nuclei*** - ***energy*** is released and, often, a ***particle*** is also ***emitted***.

For example:



an ***unstable*** *polonium* nucleus

a ***stable*** *lead* nucleus

an α-*particle*

$^{210}_{84}Po$ $^{206}_{82}Pb$ $^{4}_{2}He$

Most elements have ***isotopes***, most of which are ***unstable***. The stability of a nucleus depends on its ***proton neutron balance***;

- ***smaller nuclei*** usually 'prefer' ***equal numbers***:- *proton: neutron ratio = 1:1*

  unstable nuclei usually have *too many* ***neutrons***, so a ***neutron*** changes into a ***proton*** and an ***electron***. The ***electron*** is ***emitted*** as a β-*particle*.

  $^{1}_{0}n \longrightarrow {}^{1}_{1}p + {}^{0}_{-1}e$

  e.g. $^{14}_{6}C \longrightarrow {}^{14}_{7}N + {}^{0}_{-1}e$

- ***larger nuclei*** 'need' ***more neutrons***:- *proton: neutron ratio = 1:1.5*

  unstable nuclei usually have *too much mass*, so an α-*particle*is ***emitted*** to *reduce mass* and ***improve*** the *proton:neutron ratio*.

  e.g. $^{232}_{90}Th \longrightarrow {}^{228}_{88}Ra + {}^{4}_{2}He$

- above atomic number 83 almost all isotopes are unstable.

Other processes such as *'electron capture'* , *'neutron capture'* and *'proton emission'* are possible but the main processes are the ***emission*** of α-*particles* and β-*particles*.

Emissions

α-particles
β-particles
γ-rays

Most radioactivity involves the ***emission*** of α- and β-particles but ***energy***, in the form of *high frequency electromagnetic radiation* is also released.These γ-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***.

Property	*Type of emission*		
	α-particle	*β-particle*	*γ-rays*
nature	2 ***protons***, 2 ***neutrons*** (He nucleus)	***electron*** (n → p + e)	high ***frequency*** radiation
charge	***2+***	***1—***	0
mass	***4***	***0 (negligible)***	0
stopped by	***paper***	***aluminium*** foil	***lead*** sheet
electric field	*slightly* towards ***negative*** plate	*greatly* towards ***positive*** plate	no effect

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

Nuclear Equations

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

mass → $^{206}_{82}Pb$ ← ***charge***

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'*

Other particles that need to be learnt are:-

$^{4}_{2}He$ — **α - *particles*** (strictly speaking $^{4}_{2}He^{2+}$)

$^{0}_{-1}e$ — **β - *particles*** (slow moving electrons emitted from the nucleus.)

$^{1}_{0}n$ — ***neutrons***

$^{1}_{1}p$ — ***protons*** (sometimes represented as $^{1}_{1}H^{+}$ since a hydrogen ion is just a proton)

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***.

e.g. $^{14}_{6}C \longrightarrow {}^{14}_{7}N + {}^{0}_{-1}e$

Typical processes include:-

Alpha decay $^{230}_{92}U \longrightarrow {}^{226}_{90}Th + {}^{4}_{2}He$

Beta decay $^{216}_{84}Po \longrightarrow {}^{216}_{85}At + {}^{0}_{-1}e$

Gamma decay *this is the emission of energy so no equation possible*

Neutron capture/ Proton emission *this reaction occurs naturally in the uppper atmosphere triggered by cosmic rays*

$^{14}_{7}N + {}^{1}_{0}n \longrightarrow {}^{216}_{85}At + {}^{1}_{1}p$

Electron capture *sometimes isotopes have too few neutrons so capture an electron from their first shell and convert a proton into a neutron*

$^{37}_{18}Ar + {}^{0}_{-1}e \longrightarrow$

Nuclear Fusion *in suns, at temperatures of about 10 million K, small atoms can fuse together*

$^{2}_{1}H + {}^{3}_{1}H \longrightarrow + {}^{1}_{0}n$

'Man-made' processes include:-

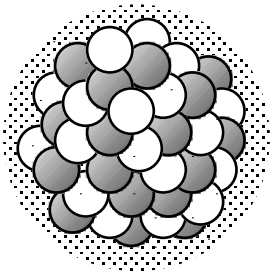
Nuclear Fission *in power stations atoms are bombarded with neutrons to form unstable nuclei which then split apart to form smaller atoms*

$^{235}_{92}U + {}^{1}_{0}n \longrightarrow \longrightarrow {}^{140}_{54}Xe + {}^{235}_{92}U + 2\,{}^{1}_{0}n$

The development of high energy particle accelerators means that just about any particle can be fired into

3.4 Nuclear Chemistry

Radioactive Decay



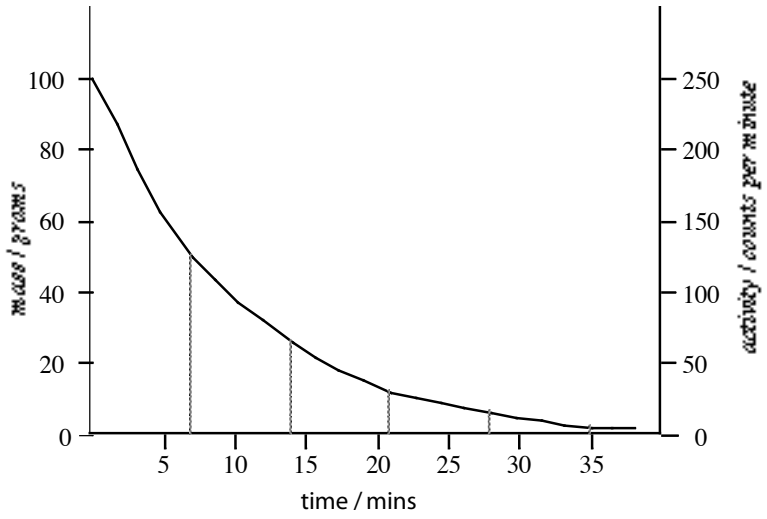
The breakdown of the ***nuclei*** of ***unstable*** atoms is known as ***decay***.

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***.

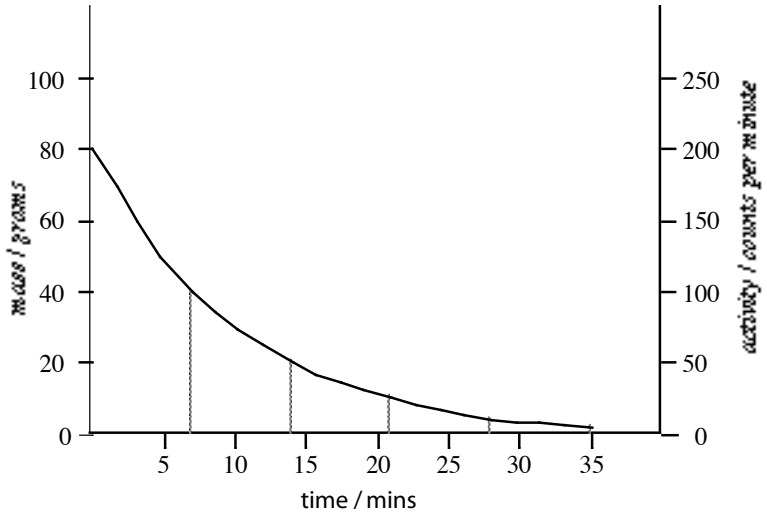


Starting with 100g of radioactive material, a ***geiger counter*** could detect 250 particles being ***emitted*** every minute.

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 ($t_{½}$)***. In the example above, the half-life, $t_{½}$, = 7 minutes.



Starting with a ***different mass***, **80**g, 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 $t_{½}$ = 55 seconds

others have a *very* ***long*** half-life e.g ^{238}U $t_{½}$ = 4.51 x 10^{9} years

We consider that an ***isotope*** is 'safe' when the level of its ***activity*** falls to the level of normal ***background radiation***. 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 and 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

cancer treatments

e.g ^{60}Co is a powerful γ-emitter used to treat deep-seated ***tumours***

^{32}P is a weak β-emitter which can be applied directly to treat ***skin cancer***

wires of ^{198}Au can be placed inside ***tumours*** to dose them with radiation

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 γ-radiation from ^{192}Ir is used to detect ***cracks*** in jet turbines

domestic smoke detectors

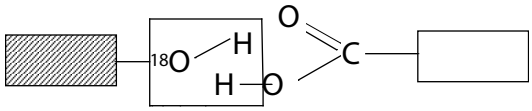
e.g. ^{241}Am emits α-particles that even a small amount of ***smoke*** blocks

measuring thickness/checking contents

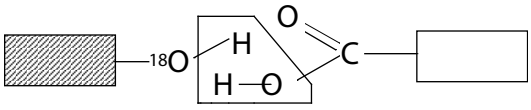
e.g. the thickness of ***steel*** sheet or the level of ***beer*** in a can can be monitored

Scientific ***reaction pathways - using isotopic labelling***

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



predicted mechanism



actual mechanism

radioactive ^{18}O should have been part of the H_2O molecule formed

in fact, ^{18}O remained as part of the ester molecule.

e.g ^{32}P was used to follow the routetaken through plants by ***phosphorous***

ADP → ATP etc

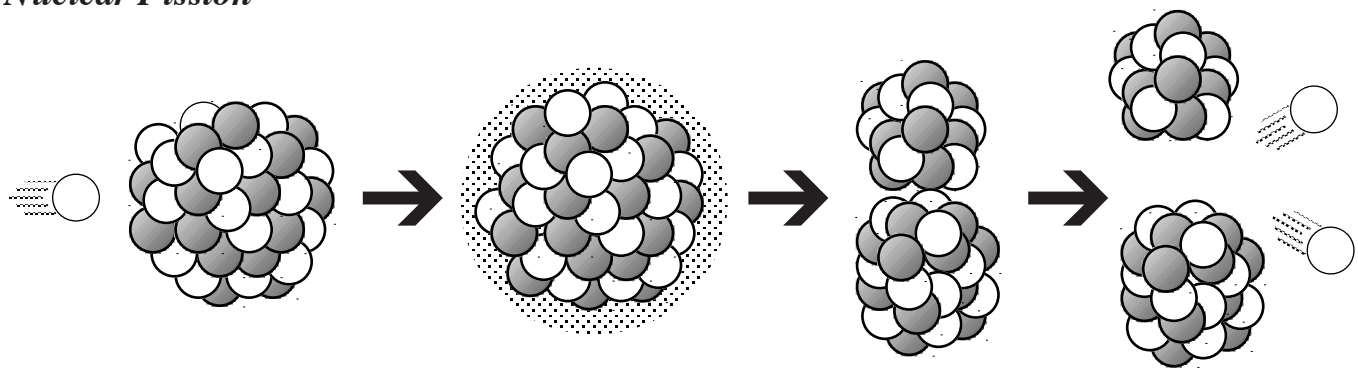
dating

e.g. ^{14}C is produced naturally in the upper ***atmosphere***. While alive, ***plants*** and ***animals*** have a constant ratio of ^{12}C:^{14}C. Once they die the ^{14}C ***decays***. The half-life for ^{14}C is about 5,600 years so the age of any object made from a living organism can be ***estimated*** by comparing it with a similar object today.

Nuclear Energy

*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:-

$$^{1}_{0}n + {}^{235}_{92}U \longrightarrow {}^{140}_{54}Xe + {}^{235}_{92}U + 2\,{}^{1}_{0}n$$

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, 235g, 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....

Advantages	***Diadvantages***
no '***greenhouse***' gases emitted	possibility of ***disastrous*** accident
no SO_2 to add to '***acid rain***'	increase in '***background***' radiation
safer ***mining*** uranium than ***mining*** coal	problems ***storing*** long term waste
uranium reserves will last longer than ***fossil fuel*** reserves	slow to change output levels to respond to peaks of demand
less ***visual*** impact than coal- or oil-fired power stations or wind farms etc	***plutonium*** produced may lead to increase in nuclear ***weapons***
fewer ***stations*** needed	much more ***expensive*** to build
	more ***expensive*** to decommission

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 $t_{½}$) ***radioactive*** products. It would replicate one of the main reaction that powers a ***star*** .

$$^{2}_{1}H + {}^{3}_{1}H \longrightarrow + {}^{1}_{0}n$$

The major difficulty is bringing ***nuclei*** together (*enormous* ***repulsion***) long enough to ***fuse*** together. Very ***expensive*** devices are being tested but, so far, no-one has achieved ***fusion*** for more than a few seconds or succeeded in producing ***more energy*** than was needed to achieve ***fusion***.

In ***stars*** and ***nebulas***, ***temperatures*** of several ***million*** degrees Celcius are attained and ***atoms*** possess so much ***energy*** that ***fusion*** can occur and larger ***nuclei*** can be formed.

$$3\ {}^{4}_{2}\mathrm{He} \longrightarrow$$

$${}^{12}_{6}\mathrm{C} + {}^{4}_{2}\mathrm{He} \longrightarrow$$

In the *heaviest*, ***hottest*** stars, even heavier ***elements*** can be produced. These heavier ***elements*** form the *core* of the ***star*** . Once iron is formed, too much energy is ***absorbed*** in the core and eventually the star will go *supernova* and ***explode***. This disperses the ***elements*** causing new *suns* and *planets* to form. All *naturally-occuring* ***elements*** have been formed in this way over ***billions*** of years.

1. *The UK chemical industry is a major contributor to both the quality of our life and our national economy*

2. *Stages in the manufacture of a new product can include **research**, **pilot study**, **scaling-up**, **production** and **review***

3. *A chemical manufacturing process usually involves a sequence of steps*

4. *A **feedstock** is a reactant from which other chemicals can be **extracted** or **synthesised***

5. *The major **raw materials** in the chemical industry are fossil fuels, air, metallic ores & minerals, and water*

6. *Chemical manufacturing may be organised as a **batch** or as a **continuous** process*

7. *Process **conditions** are chosen to maximise economic efficiency*

8. *Manufacturing costs include **capital** costs, **fixed** costs and **variable** costs*

9. *The UK chemical industry is, by and large, capital rather than labour intensive*

10. *Safety and environmental issues are of major importance to the chemical industry*

11. *Both historical and practical factors affect the location of chemical industries*

12 *The efficient use of energy is signi.ficant in most chemical processes*

13 *Factors influencing the choice of a particular route include cost, availability and suitability of feedstock(s), yield of product(s), opportunities for the recycling of reactants and marketability of by-products*

3.5 Chemical Industry

*This section does not require specific knowledge of any particular process. It is the **concepts** behind Industrial Processes that need to be appreciated. Having said that, it is easier to use a specific process like The Haber Process to illustrate these concepts.*

Research & Development

The manufacture of ammonia did not start with the building of a ***full scale production plant*** costing millions of pounds.

Small scale experiments would be conducted first to find the answers to questions such as:-

- what reagents to use
- how much of each reagent
- what temperature/pressure
- whether or not to use a catalyst
- how fast would reaction be
- how easy to separate product(s)

This would lead to the building of ***larger scale pilot plant*** which would be used to determine issues like:-

- optimum temperatures/pressures
- likely yields
- potential problems such as catalyst poisoning, construction of containers able to withstand high pressures etc.

At every stage information gathered is ***reviewed*** and ***modifications*** made to the process. Scaling up does not simply mean calculating larger quantities of reactants; temperature changes that are easy to cope with on a small scale may be a major problem on a larger scale.

Building the Plant

£

Capital Costs
Fixed Costs
Variable Costs

The plant is likely to be the major ***capital cost*** involved in the manufacture of ammonia and the profitability of the product will depend on their being adequate returns to justify the extremely high outlay.

Other ***capital costs*** will include ***Research & Development*** as well as building the ***infrastructure*** (transport etc) that will be needed to service the plant. Most companies will borrow at least some of the money needed to start up the plant.

Fixed costs will be paid regardless of how close to maximum capacity the plant is operating at; e.g *interest payments, wages, rates, land rental, plant maintainence* etc.

Variable costs are less predictable: e.g. unexpected repairs, changes in costs of *raw materials*, changes in price of fuel for transport etc.

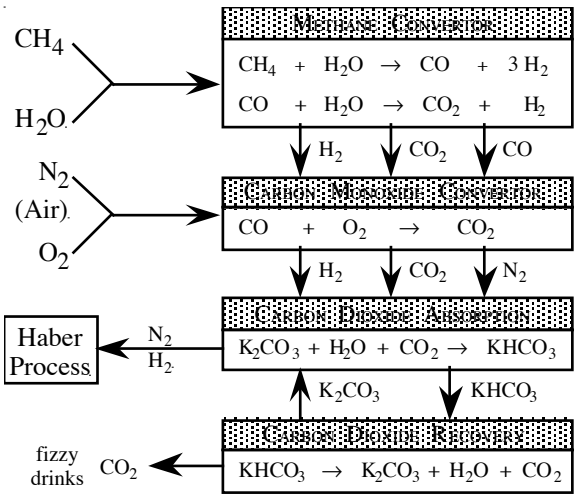
Variable costs also fluctuate depending on how close to capacity the plant is operating: e.g when demand for ammonia is low 'savings' are made because *less raw materials* are needed, *less transport* is needed, *energy costs* may be lower, charges levied for *treatment of effluents* may be lower etc.

The Haber process benefits from cheap, readily available ***raw materials*** - *air*, *water*, *natural gas* & *naptha*.

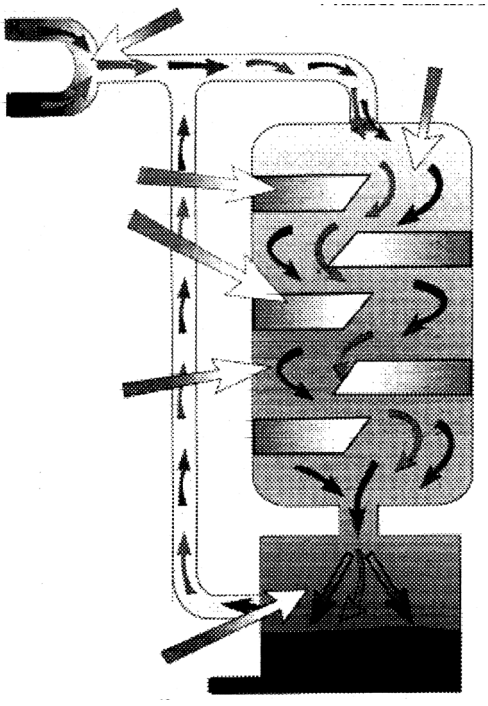
Plants are usually built next door to *oil refineries* to keep *transport costs* down.

Recycling N_2 and H_2 helps keep costs down.

Conversion of CO to CO_2 releases energy which is used to heat the iron catalyst. The CO_2 is a ***by-product*** that can be sold on to make fizzy drinks helping to keep costs down.



The Process



Having purified the N_2 and H_2 the mixture is then fed into the reaction chamber, where it flows over trays containing the iron catalyst.

$$N_2 + 3H_2 \Leftrightarrow 2\,NH_3 \quad \Delta H = -92\ kJ\ mol^{-1}$$

The reaction is reversible so, if left long enough, an equilibrium mixture would be produced.

A Low temperature would favour the production of NH_3, but would make the reaction too slow. A moderately high temperature between 400 and 500 °C is preferred.

High pressures between 25 and 150 atm are used. Higher pressures would improve yields but would not justify the *extra expense*.

Under these conditions yields of between 15 and 25% are possible. This is sustainable because the unreacted N_2 and H_2 can be easily *recycled* once the ammonia is condensed to a liquid.

The Haber Process is an example of a ***continuous process*** - *raw materials* flow in, products flow out 24 hours a day, 7 days a week. ***Capital costs*** are high but the process can be highly *automated* so *running costs* (*labour* etc) are less.

Other products would be made by a ***batch process*** - *raw materials* are loaded in, left until they have reacted and then products are removed. This is usually done on a much smaller scale so ***capital costs*** are lower. ***Batch processes*** are also *more flexible*: different chemicals can be made using the same reactor, *quality* can be easily checked and a'bad batch' rejected or recalled. Many *drugs* and *foodstuffs* are made by the ***batch process***.