

PRODUCTION of MATERIALS

What is this topic about?

To keep it as simple as possible, (K.I.S.S.) this topic involves the study of:

1. **POLYMERS FROM PETROCHEMICALS & BIOMASS**
2. **ALTERNATIVE FUELS - ETHANOL & THE ALKANOLS**
3. **REDOX CHEMISTRY & BATTERIES**
4. **RADIOACTIVITY & ITS USES**

...all in the context of society's use of energy and materials

but first, an introduction...

In the previous topic in the Preliminary Course, you learnt about **carbon chemistry** and the importance of petroleum as a fuel source.

This topic begins by taking this idea further. Petroleum not only provides fuels, but is a source of chemicals for making plastics.



To understand this, you need to learn about a vital chemical **Ethylene**, and the important industrial process of **Polymerization**.

You will learn about natural polymers, too. All living things are built from polymers, and as the **Petrochemicals** run out, we need to look to living things to provide our raw materials in the future.

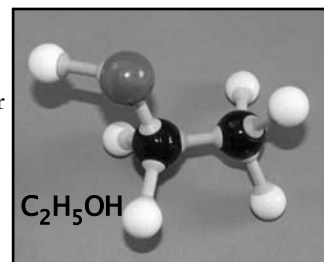
Then you will learn more carbon chemistry when you study the

alcohols

and the most important member of this group

ETHANOL

a possible candidate for replacing petrol as a fuel.



Then onto **REDOX Chemistry**,

and its involvement in electric

Cells & Batteries



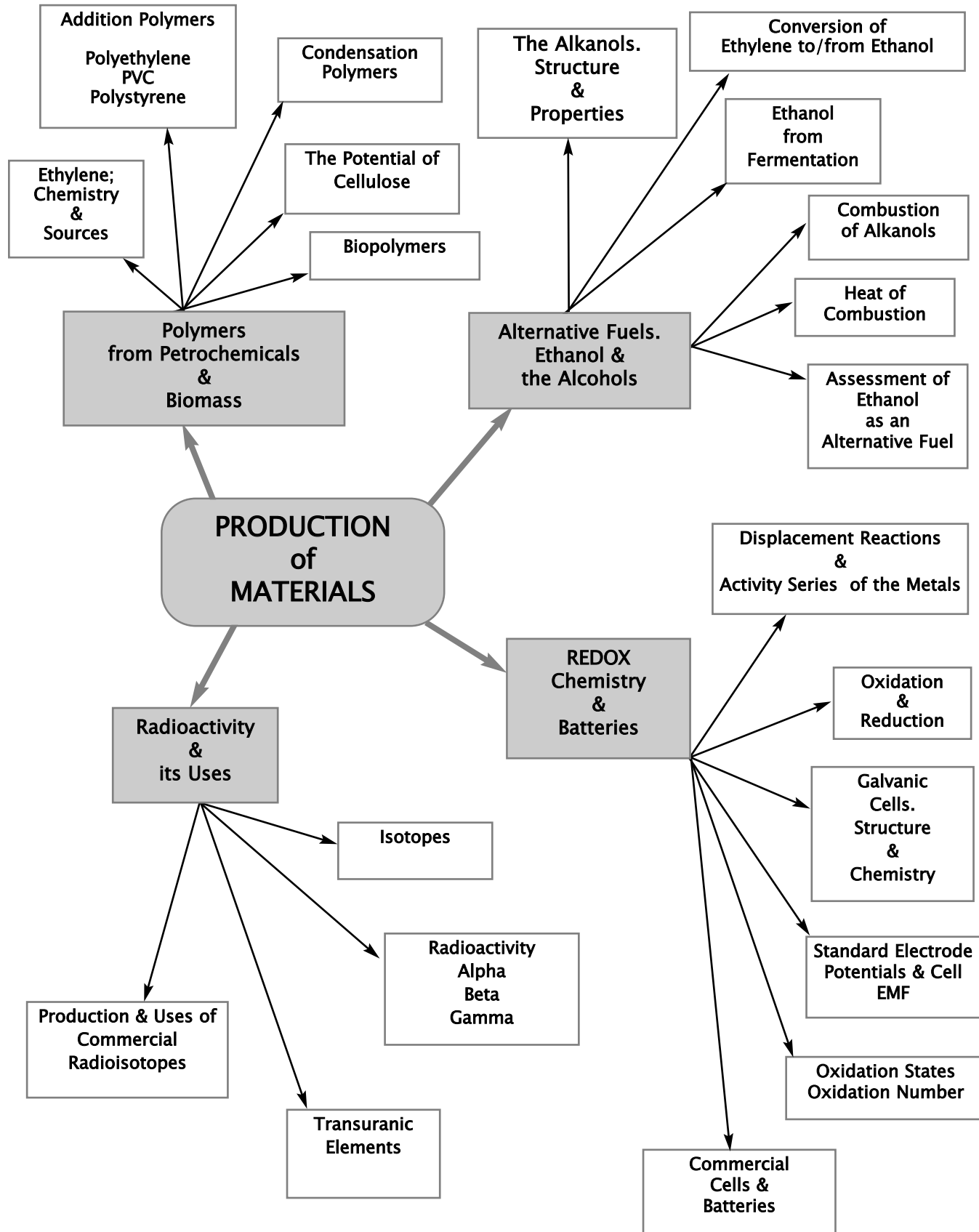
Finally, we go into the atomic nucleus to study the phenomenon of

Radioactivity



CONCEPT DIAGRAM (“Mind Map”) OF TOPIC

Some students find that memorizing the **OUTLINE** of a topic helps them learn and remember the concepts and important facts. As you proceed through the topic, come back to this page regularly to see how each bit fits the whole. At the end of the notes you will find a blank version of this “Mind Map” to practise on.



1. POLYMERS FROM PETROCHEMICALS & BIOMASS

Petrochemicals

When petroleum is refined, the major products are the fuels such as petrol and diesel. However, its not all about fuels. Our chemical industry depends on a whole range of other compounds extracted from petroleum, which are collectively called "Petrochemicals".

Petrochemicals are vital raw materials for the manufacture of

- plastics and synthetic fibres
- pigments for inks, dyes and paints
- detergents & adhesives
- cosmetics & pharmaceuticals
- explosives

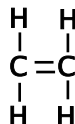
... and much more.

One of the most important petrochemicals is

Ethene (Ethylene) C_2H_4

Ethene is also known by its common name, "**Ethylene**".

This is the name favoured in the syllabus, so it will be used from here on.



Ethylene is the simplest of the Alkene homologous series. You previously learnt about the Physical Properties of the alkenes:

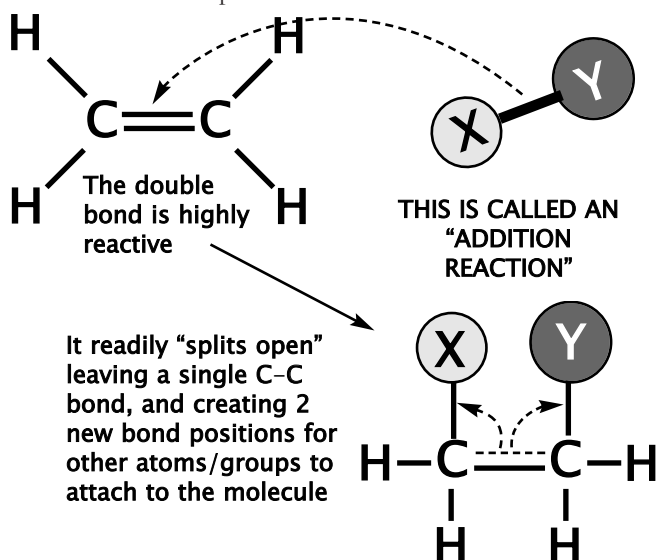
- low m.p. & b.p.'s.
- insoluble in water.
- non-conductors of electricity.

Due to non-polar bonding within, there are only weak "Dispersion Forces" between the molecules

The only Chemical Property you know about so far is that alkanes and alkenes will undergo combustion... they burn. Now you'll find out more...

Chemistry of Ethylene

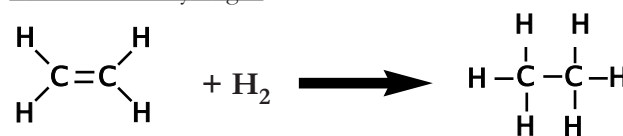
The reason that ethylene is one of the most useful chemicals on the planet is all about that double $C=C$ bond.



Addition Reactions of Ethylene

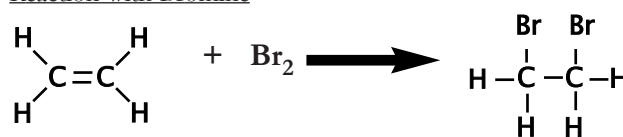
These are not required learning, but study each diagram to make sure you understand the concept of an "Addition Reaction" across the double bond

Reaction with Hydrogen



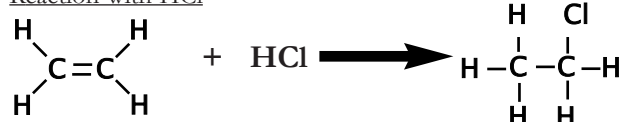
Ethylene + Hydrogen \longrightarrow Ethane

Reaction with Bromine



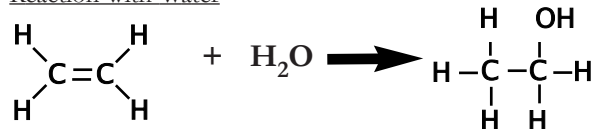
Ethylene + Bromine \longrightarrow 1,2-dibromoethane

Reaction with HCl



Ethylene + Hydrogen Chloride \longrightarrow Chloroethane

Reaction with Water



Ethylene + Water \longrightarrow Ethanol

These are just a few of the possible Addition Reactions that can occur across the double bond

Ethylene C_2H_4 is the simplest, and most important of the Alkenes.

It is one of the most important Petrochemicals because of the variety of products that can be made from it.

Its chemical versatility is due to the double $C=C$ bond which is highly reactive and allows many "Addition Reactions" to occur.

Practical Work

Identifying Alkenes with Bromine

You may have done simple experiments to learn how an alkene can be quickly and easily identified, and differentiated from an alkane.

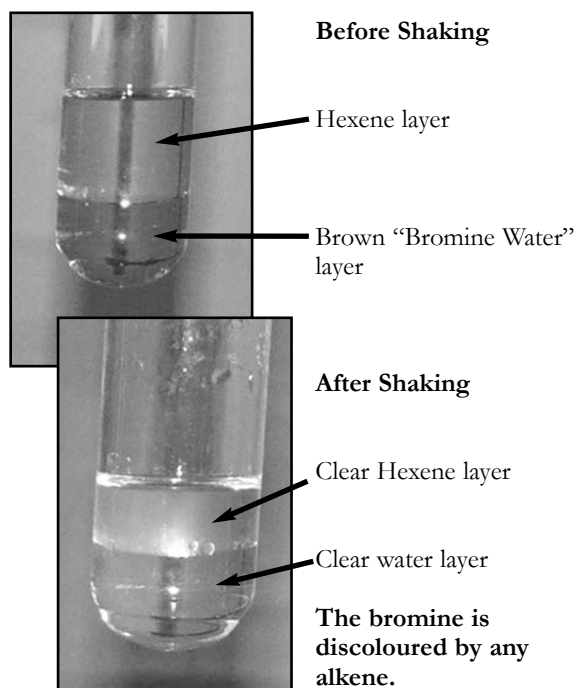
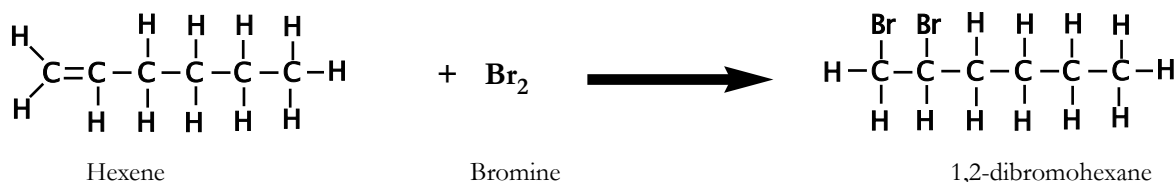
A water solution of bromine ($\text{Br}_{2(\text{aq})}$) has a brown colour.

If it is in contact with a liquid hydrocarbon, the water and the hydrocarbon form separate layers... they are immiscible liquids. Water, being denser, will always be at the bottom.

Bromine is actually more soluble in a hydrocarbon, so when shaken, it will switch to the top hydrocarbon layer, and changes colour from brown to purple.

In an alkane (hexane is often used) the colour will change and switch layers, but it will remain coloured because no reaction occurs.

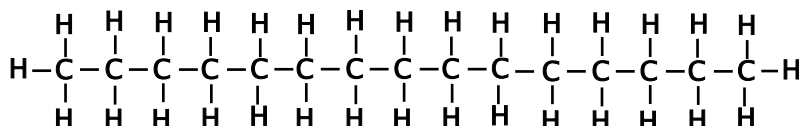
In an alkene (e.g. hexene) the bromine totally loses all colour because an addition reaction occurs.



The Industrial Source of Ethylene

Crude petroleum contains very little ethylene. When the “fractions” are separated by Fractional Distillation, there is a large fraction of low-value alkanes with 15 or more carbon atoms.

e.g. pentadecane $C_{15}H_{32}$



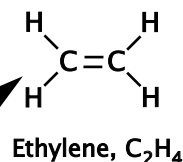
These large molecules are broken into smaller molecules by a process called “Cracking”, which can be done by simply heating (“Thermal Cracking”) or by the use of a Zeolite catalyst... “Cat Cracking”.

When the molecule is broken into fragments, some pieces form as alkanes, but others must form as alkenes, because there are no extra atoms to occupy the bond positions that are created.

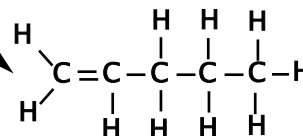
Once “cracked”, the mixture is fed back into the Fractional Distillation process. Many of the smaller molecules end up in the valuable petrol or diesel fractions.

Any ethylene formed is recovered from the gas fraction.

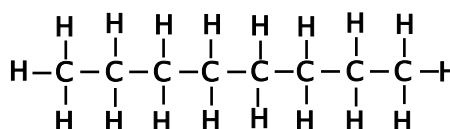
If you add up all the atoms in these 3 product molecules, you'll see that the total is the same



Ethylene, C₂H₄



Pentene, C₅H₁₀



Octane, C_8H_{18}

Ethylene
is obtained from the
“Cracking”
of long-chain petroleum fractions

Polymers

One general category of chemicals are known as "Polymers". All polymers are large molecules made by joining together many small molecules, called monomers. ("poly" = many, "mono" = one, "mer" = unit)

Many of the important molecules in living cells are polymers, for example:

- starch is a polymer of many glucose molecules.
- proteins are polymers of amino acids.
- DNA is a polymer of nucleotides, sugar and phosphate.

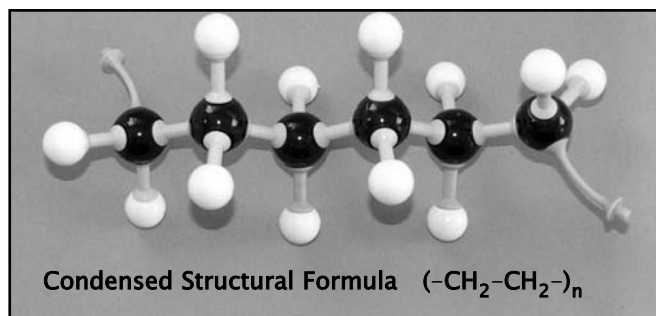
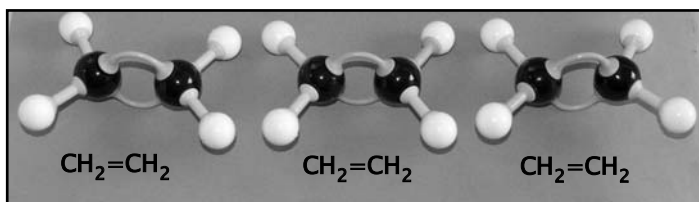
Many common, widely used substances are manufactured polymers, including all the different plastics and synthetic fibres such as nylon.

Ethylene is the starting chemical ("feedstock") in the manufacture of many polymers.

Addition Polymerization of Ethylene

Not only can ethylene carry out addition reactions with bromine, water, etc., but many ethylene molecules can react with each other.

You may have used molecular models to help visualize the process.



The result is that the ethylene monomers join together by addition reactions across the double bond. This is an "Addition Polymerization" process and results in a polymer called "Polyethylene", also known by the trade name "Polythene"

Addition Polymerization is an Addition Reaction across a double C=C bond which joins monomers to make a polymer.

Polymers can be named by adding "poly-" as a prefix to the monomer name.

Industrial Production of Polyethylene

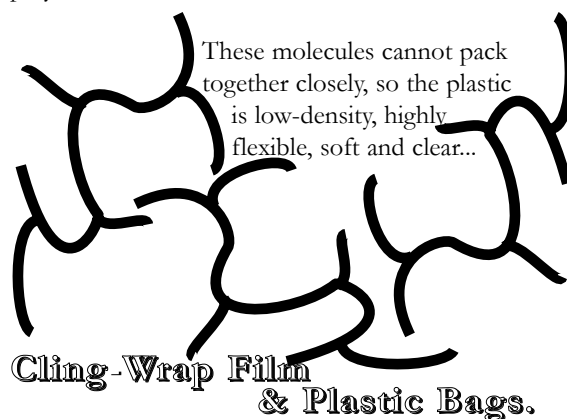
More Polyethylene is manufactured than all other plastics put together... it is one of the most used materials in our world. There are basically 2 different production methods, which produce 2 different forms of polyethylene.

Low Density Polyethylene

If the monomer ethylene is treated with

- high pressure (over 1,000 atmospheres)
- high temperature (300°C)
- an "initiator" chemical

addition polymerization occurs, with about 2,000 monomers joining to form each "super-molecule" of polymer. In this case, the initiator chemical also causes the polymer molecules to have side-branches.

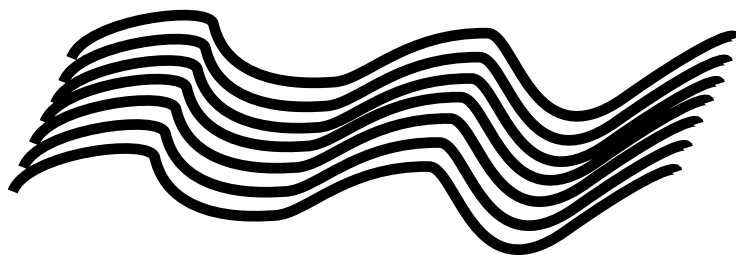


High Density Polyethylene

is manufactured

- at lower pressure (2-3 atmospheres)
- at lower temperature (about 60°C)
- with a complex catalyst

This time there are no side-branches. The long polymer molecules can pack together forming a higher-density, harder plastic used for toys, plastic utensils, and the tough, "crinkly" carry bags from shops.

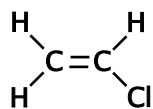


As with all materials, the uses of these plastics is closely linked to the properties they have, and their properties are controlled by their chemical and molecular structure and bonding.

This idea is taken further on the next page.

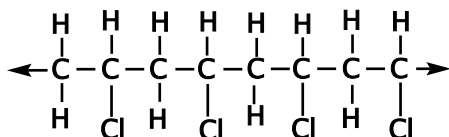
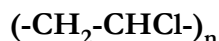
Other Important Addition Polymers

The compound chloroethene is an ethylene molecule with one hydrogen atom replaced by a chlorine.

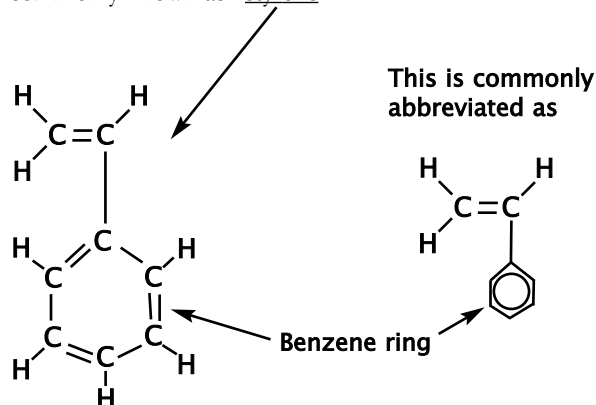


Chloroethene
is also known by its
common name
“vinyl chloride”

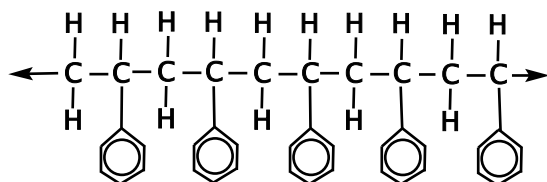
Since this molecule contains a double bond, it can undergo addition polymerization to form “Poly Vinyl Chloride” or P.V.C.



If one of the hydrogen atoms of an ethylene molecule is replaced by the ring-shaped “benzene” group, the compound has the technical name “ethenylbenzene”, but is commonly known as “styrene”.



If this undergoes addition polymerization, the polymer is “polystyrene”, so familiar in insulation, hot-drink cups, bean-bag filling, etc.



The Syllabus Requires
that you know both the
Systematic and Common Names
for these important monomers

A summary follows

Systematic Name of Monomer	Common Name of Monomer	Polymer Name(s)
ethene	ethylene	Polyethylene Polyethene Polythene
chloroethene	vinyl chloride	P.V.C. polyvinylchloride polychloroethene
ethenylbenzene	styrene	polystyrene polyethenylbenzene

Uses, Properties & Structure

The molecular structure and bonding of each plastic determines its properties, and the properties determine what uses the material is best suited for.

To keep it simple (K.I.S.S. Principle) consider just the 3 plastics above, and consider just their hardness and rigidity.

In low-density polyethylene, the molecules are long, non-polar, branched chains (diagram previous page). Being non-polar (so only weak dispersion forces operate) and unable to get close together, each molecule can bend and twist easily.

So, the plastic is soft and very flexible. It is perfect for cling-wrap film, sandwich bags and as the plastic lining in milk or juice cartons.



In P.V.C., the chlorine atoms more than double the mass of each molecule. Since dispersion forces increase with molecular weight, it means that the polymer molecules attract each other more strongly. Each molecule is held in place more, so the entire substance is harder and less flexible.

P.V.C. is a tougher, more rigid plastic. This makes it ideal for drainage pipes, guttering and electrical conduit pipes.

In polystyrene, the compact benzene side group is almost twice the mass of a chlorine atom, so the molecules are even heavier and dispersion forces stronger. Polystyrene is a hard, tough, rigid plastic, often used for making handles for cookware and hand-tools such as hammers or chisels.

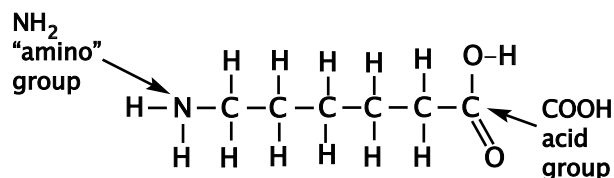
Note that the more familiar use of polystyrene is in light-weight “foam-plastic” for insulation, hot-cups and packaging. In this form it has been injected with gas to make very light, fluffy granules. The plastic itself is hard and rigid.

Condensation Polymers

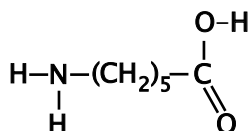
There is another way that polymers can form.

For example;

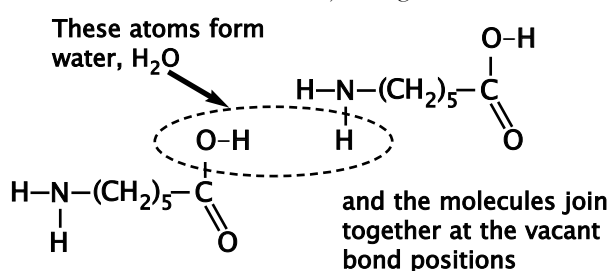
the monomer "6-aminohexanoic acid" has the structure



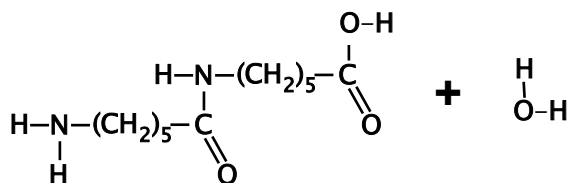
This can be abbreviated as



Two of these molecules can join together as follows



The result is:



Since a molecule of water is formed each time 2 monomers combine, this reaction is called "Condensation". Each molecule can join to another at each end, so many monomers can join in long chains... a polymer is formed.

The example above results in the polymer we call "Nylon", widely used in fabrics and clothing.

Condensation Polymers
 are formed when monomer molecules
 join together
 by eliminating a molecule of
 WATER

As well as nylon, other common condensation polymers are polyester (fabrics) and P.E.T. (drink bottles).

ALL BIOLOGICAL POLYMERS, such as proteins and starch, ARE CONDENSATION POLYMERS.

When the Petrochemicals Run Out

Petroleum is a non-renewable, fossil fuel. The estimates are that it will last only about 30 years at current usage rates. When supplies begin to run short, (this may already be happening) we will not only face a shortage of fuel, but of vital chemicals for our manufacturing industries.

Ethylene is an example of a critical petrochemical. It is one of the raw "feedstock" chemicals for making plastics, fibres and fabrics, medicines, dyes and pigments for ink and paint, cosmetics, detergents, and much more.

Eventually, and maybe sooner than we realize, we will need to find new raw material resources to replace the dwindling oil supplies. It makes sense that the new sources are renewable and sustainable, so that we can manufacture the things we need far into the future.

For renewable and sustainable, we must use living things and their products...

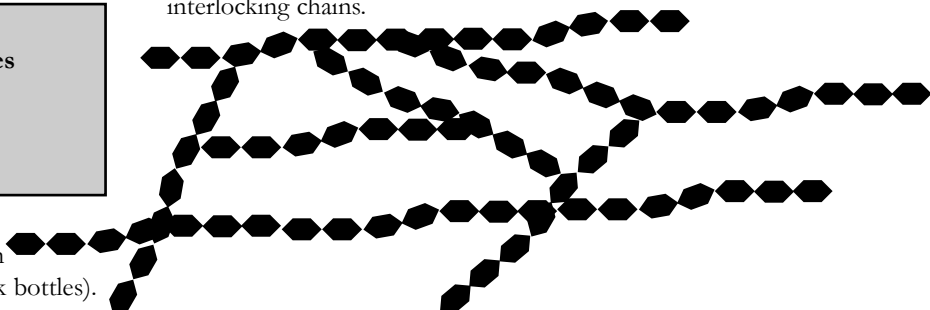
Cellulose

You may be aware that all plant cells are surrounded by a rigid cell wall which supports, protects and strengthens plant tissue. The plant cell wall is made of cellulose.



Cellulose is a condensation polymer. The monomer is glucose, the sugar made by plants during photosynthesis.

When glucose molecules join together, each pair eliminates a water molecule... a condensation reaction. To make cellulose, thousands of glucose molecules join into interlocking chains.



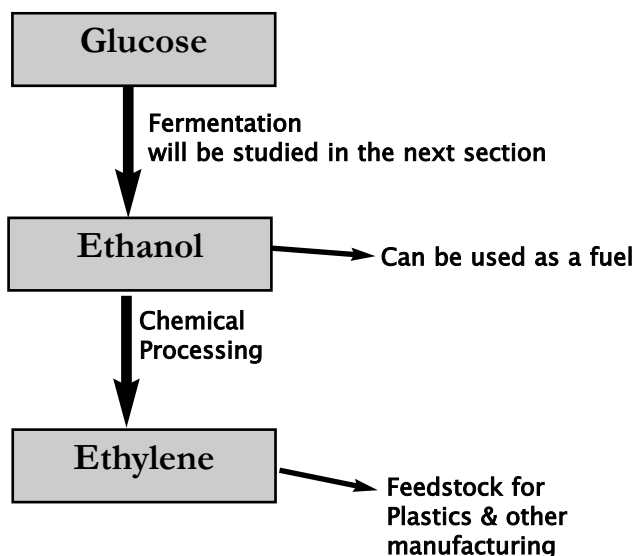
You are familiar with cellulose... it is the fibrous stuff of cotton and linen. We make enormous use of it as paper. We also waste a lot of it in the plant husks, leaves, stalks and stubble left over from our crop growing and timber industries.

Could it be better used?

Cellulose as a Future Raw Material

The glucose molecule CAN be used to replace many petrochemicals.

Simple, existing technology allows:



Unfortunately, we have not yet developed a simple, efficient and economical way to break the cellulose polymer down into molecules of glucose.

We can make ethanol and ethylene on a large scale from starch or sugar, but real sustainability will come by being able to use the cellulose in all the “waste” plant matter.



Photo by Maciej Ciupa

Biopolymers

The word “Biopolymer” refers to those naturally occurring polymers made by living things, such as starch and cellulose. Humans have always used these polymers (e.g. using cotton for clothing) and for nearly 100 years have been using chemically modified versions of them. For example, “rayon” is a synthetic fibre made from modified cellulose.

Research has been going on for many years on ways to get living things to make polymers with properties more like those of the useful petrochemical-based plastics.

A lot of the research has centred around the polymer “polyhydroxybutyrate” (PHB) which has properties not too different from polyethylene. It was discovered 80 years ago that PHB can be made by bacteria, such as the species *Bacillus magaterium*.

In recent years, the Monsanto company has used Genetic Engineering (G.E.) to transfer the genes for PHB production into corn plants. The crop is grown, harvested and eaten as usual, but then the stalks and leaves are harvested for their PHB content, which is as high as 20% of the dry weight.



Photo by Luis Rock

Analysis

- PHB has properties which make it suitable to replace some plastics for packaging, but it tends to be brittle, and extra breakages must be accepted.
- PHB has the major advantage of being biodegradable, but this also limits its range of uses, since it can rot and disintegrate during use.
- There is resistance from farmers and consumers regarding the use of G.E. plants.
- The production of PHB is not yet as cheap as using petrochemical plastics.

Conclusion: PHB grown in corn has potential, but is unlikely to become widely used yet.

Worksheet 1

Fill in the Blank Spaces

When petroleum is refined the main products are a)....., but there are also other chemicals extracted for use in manufacturing. These chemicals are collectively called “b).....” and the most important is c).....

The reason for ethylene’s great usefulness is the d)..... carbon-carbon bond. This bond is highly e)..... and readily “splits open” allowing other atoms/groups to join onto the molecule. This is called an f)..... Reaction.

In the laboratory, compounds containing a double bond can be identified using a solution of g)..... If this is added to an alkene, the g)..... will be h)..... because of an addition reaction. With an alkane, the colour may change and shift from one solvent to the other, but will not be h).....

The yield of Ethylene from petroleum is greatly increased by the process of “i).....” in which long-chain alkanes are broken into smaller fragments by either j)..... or This increases the yield of valuable fuel fractions such as k)..... and increases the yield of ethylene which is extracted from the l)..... fraction.

The major use of ethylene is the manufacture of m)..... Thousands of ethylene monomers join together by n)..... reactions to form o)..... If the reaction is carried out at high p)..... and with an “initiator” chemical, the result is q).....-density polyethylene. The long chain molecules have many r)..... and cannot pack close together, so the plastic is soft and s)....., ideal for soft plastic bags and t)..... film.

If the reaction is carried out at lower pressure and temperature with a u)....., the polymer molecules lack branches and can v)..... to form w).....-density polyethylene, used (for example) in “crinkly” x)..... from shops.

Other important polymers are:

• P.V.C. which stands for y)..... The monomer is commonly called z)....., but its correct chemical name is aa)..... The added chlorine atom makes the molecular mass much higher, so that the ab)..... forces between molecules are stronger. The plastic is ac)..... and more ad)..... so it is used for ae).....

• Polystyrene is made from the monomer af)..... for which the correct systematic name is ag)..... The “side group” on this molecule is the ring-shaped ah)..... group. This increases the molecular mass so that the ai)..... forces hold the polymer molecules even more strongly so the plastic is aj)..... and

Polymers can also form by a ak)..... reaction. This occurs when 2 monomer molecules join together by elimination of a al)..... Examples of condensation polymers are nylon, am)..... and All biological polymers, such as an)..... and are condensation polymers.

One important biological polymer is ao)..... which is a polymer of ap)..... and is found in large amounts in all plants, where it forms the cell aq)..... which strengthens and protects all plant tissues. We already use cellulose for fabrics such as ar)..... and and process it to make as)..... When the petroleum supplies run out, cellulose has great potential to supply our needs.

Its monomer at)..... can easily be turned into the alcohol au)..... which can be used as a fuel, or chemically converted to av)..... to feed the plastics industry. Unfortunately, we have not yet developed a simple, efficient and economical way to convert cellulose to aw)..... to begin the process.

Research is also progressing in the use of engineered “Biopolymers” such as ax)..... (abbreviation). This polymer has properties similar to some petrochemical plastics, but is made naturally by microbes such as the bacterium ay)..... (scientific name). The Monsanto company has used az)..... techniques to transfer the genes for PHB into ba)..... plants. After normal growth and harvesting, PHB can be extracted from the “waste” leaves and stems of the crop.

Although this is very promising, it is unlikely to be used on a large scale while cheaper petrochemicals are still available.

**WHEN COMPLETED, WORKSHEETS
BECOME SECTION SUMMARIES**

2. ALTERNATIVE FUELS - ETHANOL & THE ALKANOLS

The Alkanols (Alcohols)

You should recall that the Alkanes and Alkenes are 2 “Homologous Series” of compounds. In each series, the compounds follow a pattern of having the same basic structure, and are able to be described by a general molecular formula.

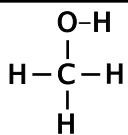
Series	General Structure	Formula
Alkanes	all single C-C bonds	C_nH_{2n+2}
Alkenes	one C=C double bond	C_nH_{2n}

Now you are introduced to another important Homologous Series... the **Alkanols**, also known as “Alcohols”.

The alkanols contain all C-C single bonds, but on one of the carbon atoms there is an -OH group... an oxygen atom and hydrogen atom.

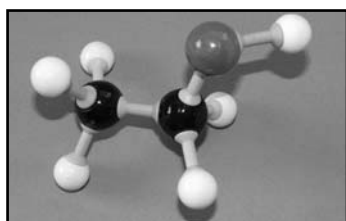
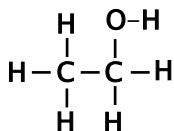
To name any **ALKANOL**
add “-ANOL” to the appropriate prefix.
General Formula $C_nH_{2n+1}OH$

Methanol CH_3OH
(Formula could be written CH_4O , but it is usual to emphasize the -OH group)



Ethanol C_2H_5OH

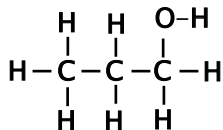
This is by far, the most important member of the series.



Condensed Structural Formula



Propanol C_3H_7OH
 $CH_3CH_2CH_2OH$

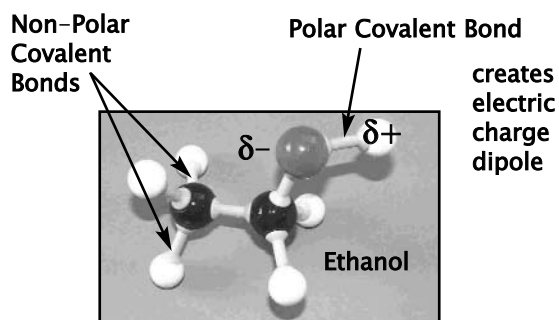


and then...

Butanol	C_4H_9OH	$CH_3(CH_2)_2CH_2OH$
Pentanol	$C_5H_{11}OH$	$CH_3(CH_2)_3CH_2OH$
Hexanol	$C_6H_{13}OH$	$CH_3(CH_2)_4CH_2OH$
Heptanol	$C_7H_{15}OH$	$CH_3(CH_2)_5CH_2OH$
Octanol	$C_8H_{17}OH$	$CH_3(CH_2)_6CH_2OH$

Properties of the Alkanols

What a difference that oxygen atom makes!



The polar covalent bond in the -OH group creates a charge dipole, and strong **hydrogen bonding** exists between the molecules.

This results in:

- mp's and b.p's being much higher than the corresponding alkanes. The first 8 alkanols are all liquids at room temperature.

- smaller alkanols are soluble and fully miscible in water, because they can form hydrogen bonds with water molecules. The larger ones become less soluble as the non-polar hydrocarbon chain grows longer.

- the alkanols (especially ethanol) are excellent solvents, able to dissolve many water-soluble (polar) solutes, but also able to dissolve many non-polar substances which do not dissolve well in water. This is why ethanol is widely used in industry to dissolve reagents, pharmaceuticals and food chemicals. Around the home “methylated spirit” is used as a cleaning agent... it dissolves things well.

(Methylated Spirit, or “metho” is about 95% ethanol with water and small amounts of additives to make it distasteful to discourage anyone from drinking it)

- alkanols are inflammable, and can be used as fuels, although their energy content is not as high as the corresponding alkanes.

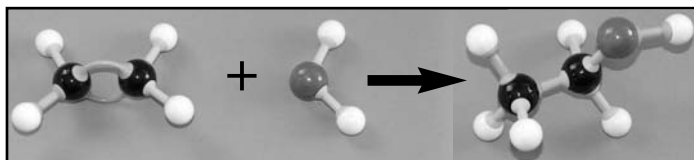
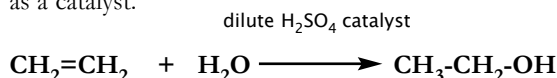
Ethanol is, of course, the alcohol in beer, wine and spirits. These are made by the process of **fermentation** carried out by living microbes, especially yeast, which is a single-celled fungus organism.

You should be aware that, despite our society's acceptance of the consumption of alcohol as a social drug, all the alcohols are toxic. Our bodies can tolerate ethanol in small doses, but others such as methanol or propanol, are quite deadly.

Ethylene to Ethanol

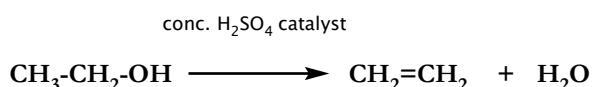
Ethylene can readily be converted to ethanol by an Addition Reaction across the double bond. You may have used molecular model kits to help visualize this reaction.

The reaction is facilitated by dilute sulfuric acid, which acts as a catalyst.



Ethanol to Ethylene

The reverse reaction is also possible:

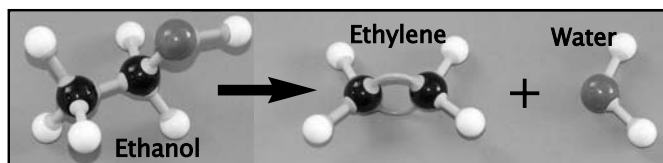


Once again a catalyst is needed to make the reaction run at a practical rate for an industrial process. The same catalyst, sulfuric acid, is used but in concentrated (not dilute) form.

Since water is produced as a product, it is reasonable to describe the reaction as a “Condensation”, but it is also known as a “Dehydration”, meaning to “take water from”.

The significance of this reaction is that ethanol can be made from plant materials, by processes that are renewable and sustainable. Making ethylene from ethanol would result in a major chemical resource being available without the use of petrochemicals.

Model of Ethanol Dehydration



Fractional Distillation

of Your “Home-Brew”

Heat gently and monitor the vapour temp. Collect the fraction produced at about 80°C.

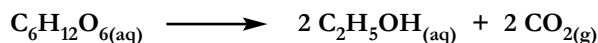
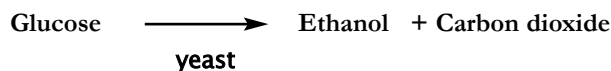
To test your distillate: pour into a watch glass and ignite carefully in a darkened room or fume-cupboard. If it burns with a blue flame, your distillate is 80-90% ethanol.



Fermentation of Sugar to Ethanol

The fermentation process is the oldest known chemical process used by humans. We don't really know when it was discovered by ancient peoples, but the brewing of beer and wine was practiced by all the early civilizations of the Middle East, Europe and Asia.

The overall chemical reaction is very simple:



It looks simple enough, but the actual chemistry is very complicated, involving many separate steps, each catalysed by a different enzyme produced by the living yeast cells.

However, you don't need to know all those details, and just like any maker of home-brew beer soon finds out, it really is simple as long as you provide certain conditions. For fermentation to work there must be:

- a suitable carbohydrate source. This can be sugar from fruit, starch from wheat, corn, potatoes, etc. (Note that the yeast is able to digest starch and other carbohydrates to glucose, so it is not necessary to actually start with glucose.)
- live yeast.
- a temperature kept fairly constant around 22-25°C.
- anaerobic conditions (i.e. no oxygen available). If oxygen is available, the yeast will produce only CO₂ and H₂O, but no alcohol.

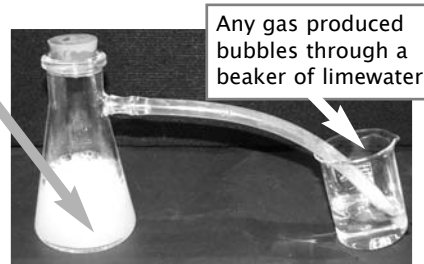
Practical Work Fermentation

You may have carried out an experiment with fermentation which is essentially a little “home-brew” exercise.

The photo shows a typical laboratory set-up.

Sealed flask contains sugar & yeast.

Temp. kept at about 25°C



You may have weighed the flask before, and after, several days of fermentation. It will have lost mass due to the loss of gas.

You would also observe bubbling in the flask over several days, and the limewater would rapidly go “milky” proving that the gas produced is CO₂.

When the bubbling subsides, the contents of the flask may have the yeasty, alcohol smell of beer.

You may have even distilled your brew to collect ethanol, as described at left.

Getting Pure Ethanol

Even under ideal conditions the fermentation of sugar to ethanol by yeast can only produce a “brew” with about 15% ethanol. At about this level, the yeast is killed by the alcohol, and no further fermentation takes place.

To get close to pure ethanol, the fermented liquor must be distilled. In the making of brandy, whiskey, rum, etc, the “spirit” is usually around 40% ethanol.

Fractional distillation will yield a distillate which is about 95% ethanol, which is quite suitable as a fuel.

The Industrial Process Today

Due to the cheap availability of petrochemicals, most of the ethanol used as an industrial solvent or for cleaning (i.e. non-drinking purposes) is made from ethene by the addition reaction with water, and NOT from the fermentation of sugar.

The only industrial-scale use of fermentation to make high-purity ethanol is in the sugar industry. A major waste product from sugar refining is “molasses” which contains a large amount of sugar. Rather than waste it, molasses is used as the sugar source for yeast fermentation, and the fermented liquor is distilled for the ethanol.

In Australia, the sugar industry is based in Queensland, and this is where the sugar-to-ethanol production takes place. Apart from producing the famous “Bundy” rum, the ethanol produced is used for:

- manufacture of vinegar.
- “extending” petrol by adding 10% ethanol. (more later)
- industrial and pharmaceutical solvent.
- domestic cleaner, in the form of “metho”.



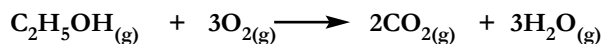
Combustion of the Alkanols

Ethanol has been mentioned as a possible fuel, so what is the chemistry of the combustion?

Basically it is the same as combustion of the alkanes:



Example: Combustion of Ethanol



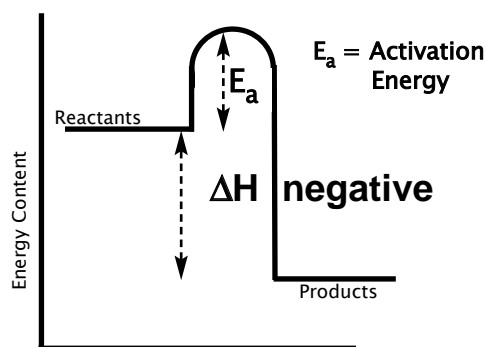
The only tricky part is balancing... be careful balancing the oxygen atoms, noting that there is already 1 oxygen atom on the left side in the alkanol molecule.

Try the worksheet at the end of this section

Heat of Combustion of a Fuel

How much energy is actually released when a fuel burns?

All combustion reactions are exothermic, so the energy profile is



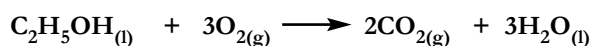
Although technically the value for ΔH is a negative quantity, for “Heat of Combustion” the value is usually written as a positive quantity because the formal definition is:

The Molar Heat of Combustion is the heat given out when 1 mole of a fuel is burned completely, with all reactants and products in their “standard states” at SLC.

Notes:

1. Since the definition is the “heat given out”, it follows that the value is expressed as a positive quantity. You must remember that combustion is exothermic, and technically it has a negative value, for example when using an equation such as $\Delta H = -m\Delta T$.
2. You learned previously that fuels generally burn only after being vaporized, and that the water forms in the gas state, as shown in the equation above. However, the definition demands that all substances are in their “standard states” at SLC, so both ethanol and water must be in the liquid state.

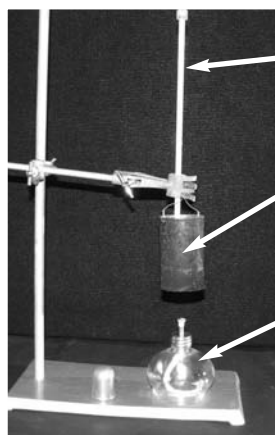
So, the Molar Heat of Combustion (ΔH_c) of ethanol would be the (positive) quantity of heat released when 1 mole of ethanol (=46.1g) burns as follows: (note the states)



Prac Work

Measuring ΔH_c of Alkanols

You may have carried out experiments to measure and calculate values for the Heat of Combustion of several alkanol fuels. A typical school experimental set-up is shown:



Thermometer measures temp. change in water.

Metal can holds a measured quantity of water. It acts as a **calorimeter**, absorbing heat released by the fuel.

“Spirit burner” burns an alkanol fuel using a wick. Burner is weighed before and after to measure the mass of fuel used.

Typical results using Ethanol:

Mass of ethanol burnt = 0.80g

Mass of water in metal can = 100g

Starting temperature of water = 16°C

Final temperature of water = 42°C

ΔT = 26°C

Analysis of Results:

Heat absorbed by water in the calorimeter:

$$\begin{aligned}\Delta H &= -mC\Delta T \quad (C = \text{Specific Heat Capacity of} \\ &= -100 \times 4.18 \times 26 \quad \text{water} = 4.18 \text{ J/}^\circ\text{C/g}) \\ &= -10,868 \text{ J} \\ &\equiv \mathbf{11 \text{ kJ of heat released.}}\end{aligned}$$

This is the heat released for 0.80g of ethanol burnt.

\therefore Heat of Combustion per gram = $11/0.80 = \mathbf{13.75 \text{ kJ/g}}$

MM(ethanol) = 46.1g

\therefore **Molar Heat of Combustion** = $13.75 \times 46.1 \equiv \mathbf{630 \text{ kJmol}^{-1}}$.

Discussion:

The “text book value” of ΔH_c (ethanol) = 1367 kJmol^{-1} .

Typically, in a school experiment, values of only about half, or less, are obtained. Why?

The analysis of results assumes that all the heat released by the burning fuel is absorbed by the water in the “calorimeter” can. However, this calorimeter is very primitive and inefficient. A lot of (most of?) the heat of the fuel can escape into the surroundings, and therefore does not get measured.

The set-up can be improved by using a larger can, wind baffles, insulation, etc., but will always give results well below “text” values.

Comparing ΔH_c of Fuels

The syllabus requires that you measure and compare the Heat of Combustion for at least 3 different alkanols, on a per gram, and per mole basis.

Hopefully you’ve done exactly that. To help you understand the figures, here is a summary of typical results. For comparison purposes, values for an alkane fuel (octane is a typical component of petrol) are included.

Fuel	Heat of Combustion Values			
	School Experiment		“Text”	
	kJ/gram	kJmol ⁻¹	kJ/gram	kJmol ⁻¹
Methanol	10	350	22.7	726
Ethanol	11	630	29.7	1367
Propanol	12	720	33.6	2021
Butanol	14	1040	36.1	2676
Octane	-	-	47.9	5470

Although the values that are typically obtained in a simple school experiment are well below the accepted “text” values, the trends are the same: the Heat of combustion of the alkanols increases steadily (on both per gram and per mole basis) with increasing molecule size.

It is notable also, that ethanol’s ΔH_c is much lower than the typical value for the compounds found in petrol. This means that ethanol, a candidate to replace petroleum fuels, is a much lower-energy fuel.

Ethanol as a Renewable Fuel

The use of ethanol as a fuel to eventually replace petrol, as the petroleum supplies run out, has been proposed because:

- the technology to make ethanol from the fermentation of sugar (followed by distillation) is a well known and proven process... we know it can be done.
- sugar for ethanol production can be harvested from plants, so it is a renewable, and sustainable energy source.
- when ethanol from plants is burnt, the carbon dioxide released is exactly the same amount that was absorbed by the plants during photosynthesis to make the sugar. Therefore, the use of plant-derived ethanol does not contribute to the “Greenhouse Effect”.

There is no doubt that ethanol can be considered as a renewable fuel.

However, that’s not the whole story...

Using Ethanol as an Alternative to Petrol

Ethanol can be added to petrol in mixtures up to about 10-20% and burnt in car engines without any modifications needed, and with only a slight loss of engine performance.

This use of ethanol as an “extender”, to conserve petrol and help reduce Greenhouse emissions has been around for years on a small scale. Following the fuel price crisis of 2005, the Australian Government has proposed making it happen on a very large scale.

As long as the ethanol is being made from the wastes of the sugar industry, and used only at about the 10-20% level with petrol, this strategy seems both economical and scientifically sound.

To run vehicles on pure ethanol fuel however, requires a total new engine design to allow for the fact that ethanol tends to be corrosive, has a different energy content, ignition temperature and burn characteristics.



The cost of setting up factories to make a totally new engine design is such that it is very unlikely that ethanol will be used as any more than a 20% fuel-extender anytime soon.



Sugar Cane Harvesting

Photo ©Robert Lincoln 2006
Used with permission

Advantages & Disadvantages of Ethanol Fuel

Some of the **Advantages** have already been discussed:

- Ethanol is a renewable fuel, when made from sugar.
- The technology is already known and proven.
- It is “Greenhouse-friendly”.
- It can be mixed with petrol up to about 20% and used without any modifications to existing engines.

This, however, is only part of the story...

Disadvantages and Difficulties

- To totally replace petrol with ethanol, the use of sugar industry wastes would be nowhere near enough. Huge tracts of land would have to be dedicated to growing sugar cane (or other crops) to supply the ethanol industry. The attempt by Brazil to do exactly this in the 1980's was an economic failure, and disrupted a lot of their food production farming to make way for “ethanol farming”.
- The current technology for ethanol production requires massive amounts of energy for the distillation process. Currently, fossil fuels are used for the heating, and so the process is not as renewable nor “Greenhouse-friendly” as first thought.
- As mentioned at left, entirely new engines are needed to run on pure ethanol. The cost of the change-over, to both manufacturers and car-owners is too high to be feasible.

Assessment

Weighing up advantages and disadvantages, the following conclusions seem realistic:

- The use of about 10-20% ethanol (derived from sugar industry wastes) to extend petrol seems likely to continue and even become more widespread.
- The use of pure plant-derived ethanol fuel seems very unlikely until one or both of these technologies develops;
 - efficient production of glucose from cellulose, derived from crop wastes, so that no crops have to be grown just for ethanol production.
 - renewable energy sources (e.g. solar power) to operate the distillation process for ethanol.

Worksheet 2

Part A Fill in the Blank Spaces

The Alkanols are an a)..... series of carbon compounds with general formula b)..... They are also known as the “c).....” Each alkanol has an d)..... group attached to one of the carbon atoms. This group contains a e)..... covalent bond which creates an electric f)..... on the molecule. This causes quite strong g)..... bonds between the molecules, which result in the following properties:

- m.p.’s & b.p.’s are much h)..... than the corresponding alkanes.
- alkanols are generally i)..... in water.
- they are excellent j)....., because they can dissolve both k)..... and (opposites) solutes.
- they are inflammable, and can be used as l)....., although their m)..... is lower than the alkanes.

Ethylene can be converted to ethanol by an n)..... reaction, adding o)..... across the double bond. Dilute p)..... acts as a catalyst for this reaction. The reverse reaction, converting q)..... to is also possible if r)..... H_2SO_4 is the catalyst. This reaction could be considered as a “condensation”, but is usually referred to as “s).....”

Biologically, ethanol can be made from t)..... by the process of u)..... The catalysts are the v)..... in living w)..... cells. The requirements for the reaction are:

- a suitable source of x)..... from fruits or grains.
- live y).....
- at temperature maintained around z)..... °C
- aa)..... conditions (no oxygen).

Fermentation can produce a mixture containing a maximum ab).....% ethanol. This can be purified by ac)..... to obtain about ad).....% purity. Industrial scale fermentation (apart from beer & wine production) uses wastes from the ae)..... industry, and then fractional af)..... to obtain near-pure ethanol for manufacturing ag)..... (food use) or for solvent and cleaning purposes.

When alkanols burn, the products of complete combustion are ah)..... and The “Molar Heat of Combustion” is defined as ai)..... with all reactant & products in their aj).....

Although the reaction is always ak).....-thermic and should have a al)..... value for ΔH , the value is stated as a am)..... quantity because of the definition.

Generally, the values for ΔH_c for the alkanols an)..... with increasing molecular size, but are much lower than the values for an ao).....

The advantages of using ethanol as a fuel are

- it is a ap)..... resource
- the aq)..... is known & proven
- it is “ar).....-friendly”
- it can be mixed with petrol to about as).....% without any modifications to existing car engines.

Disadvantages include:

- to totally replace petrol, vast areas of land would have to be at).....
- large amounts of energy are needed for the au)..... process, and we cannot yet do this in a renewable and eco-friendly way.
- vehicle av)..... would have to be totally re-designed and replaced to run on pure ethanol.

Part B Practice Problems

1. Combustion Equations for Alkanols

Write a balance equation for the complete combustion of

- | | |
|-------------|-------------|
| a) methanol | b) propanol |
| c) hexanol | d) octanol |

2. Heat of Combustion Problems

a) In an experiment, 1.4g of butanol was burnt and the heat collected by a metal can containing 200g of water. The water temperature rose by 23°C.

- Write a balanced equation for the combustion, showing all chemicals in their standard states.
- Calculate the value of ΔH_c per gram & per mole.

b) In a similar experiment using pentanol, 0.50g of fuel was burnt, which raised the temperature of 150g of water from 18 to 30°C.

- Write a balanced equation for the combustion showing all chemicals in their standard states.
- Calculate the value of ΔH_c per gram & per mole

c) The accepted value for $\Delta H_c(\text{ethanol}) = 1367 \text{ kJmol}^{-1}$. If 2.80g of ethanol was burnt in a “perfect” calorimeter containing 500g of water, by how much would the temperature of the water rise?

d) The accepted value for $\Delta H_c(\text{pentanol}) = 3330 \text{ kJmol}^{-1}$. If 0.50g of pentanol was burnt in a “perfect” calorimeter containing 150g of water, by how much would the temperature of the water rise?

Compare your answer to the data in Q(b) and comment.

3. REDOX CHEMISTRY & BATTERIES

Displacement of Metals From Solution

And now for something completely different, we go back to some Chemistry you learned in Preliminary topic 2 “Metals”. Remember the **Activity Series of the Metals**?

Most Active		React readily with
	K	
	Na	• oxygen
	Li	• water
	Ba	• acid
	Ca	
	Mg	
	Al	
	Zn	
	Fe	
	Sn	
	Pb	
	Cu	
	Ag	
	Au	
Least Active		No reaction, or very slow

Decreasing reactivity

One of the best “hands-on” ways to see the Activity Series in action is to place a piece of metal into a solution containing the ions of a less-active metal. This experiment is not actually specified by the syllabus, but hopefully you have seen what happens.



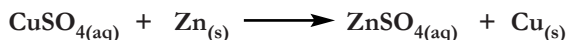
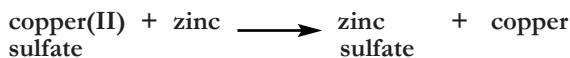
Example:

Drop a piece of zinc into copper(II) sulfate solution.

A reaction occurs which slowly “eats away” the zinc, and a solid deposit forms at the bottom. Later, the deposit is seen to be orange-coloured... it is copper metal.

The zinc has dissolved, and displaced the copper ions from solution.

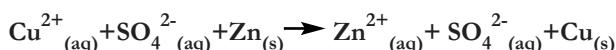
The reaction is



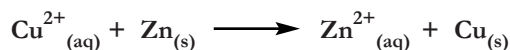
This is a “**Metal Displacement**”. It will occur whenever a metal is placed into a solution containing ions of a less-active metal. The reverse will not react.

Transfer of Electrons

The equation above can be re-written in ionic form:

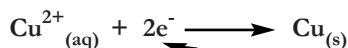


Look carefully and you will see that the sulfate ions (SO_4^{2-}) have not changed at all... they are “spectators” and can be left out, to form the “net ionic equation”:

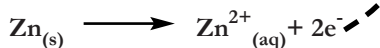


Now you can see what really happened; copper ions turned into copper atoms, and zinc atoms turned into zinc ions. This can only happen if:

each copper ion gains 2 electrons



and each zinc atom loses 2 electrons



Electrons transferred

This is one of the most common and important general types of chemical reaction; when electrons are transferred from one chemical species to another.

Loss of Electrons = “**OXIDATION**”

Gain of Electrons = “**REDUCTION**”

Reactions where this occurs are called “**OXIDATION-REDUCTION**” or simply

“REDOX”

Note that neither part can occur alone. To lose electrons, there must be another species to accept them, and to gain electrons, there must be another species to give them.

REDOX and the Activity Series

Now the Activity Series of the metals can be seen in a new way.

- Metals higher up the Activity Series have a greater tendency to be **oxidized** (= lose electrons) and so their atoms readily form ions by reacting with acids, oxygen, water, or the ions of less active metals.
- Metals lower down the Activity Series have a greater tendency to be **reduced** (= gain electrons). Their atoms are less likely to react with acids or oxygen, and their ions are more likely to be displaced from solution by more active metals.

You should recall also, that less active metals are easier to extract from their ores, (or may even be found uncombined in nature) while more active metals require more and more energy to extract from their ores. Extracting any metal from its ore involves reducing the metal's ions, so this idea links to that above.

Galvanic Cells

Just because Oxidation & Reduction must always occur together doesn't mean that they must occur in the same container.

It was discovered about 200 years ago that the 2 processes can be separated to 2 different locations, so long as there is a conducting wire to allow the flow of electrons from the site of oxidation to the site of reduction.

This forms a "Galvanic Cell" which is the basis of all our electric cells and batteries.

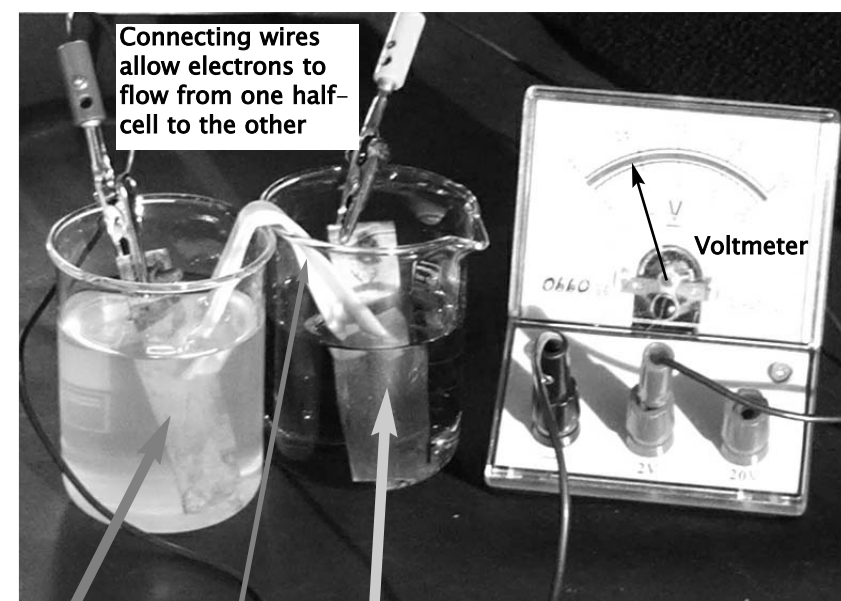
"Galvanic" is named for one of the pioneering scientists, the Italian Luigi Galvani who lived 200 years ago. At that time, electron transfer and REDOX chemistry was NOT understood.



Prac Work: Galvanic Cells

You may have done several experiments to investigate the construction of simple Galvanic Cells, and to measure the **voltage** ("potential difference") produced by different combinations of metals.

A typical experimental set-up is shown.



Zinc electrode in solution of zinc ions

Copper electrode in solution of copper ions

They must be connected by a "salt bridge" for ion transfer

Each beaker is a "half-cell", containing a metal electrode dipping into a solution of ions of the same metal.

What You May Have Discovered

Conditions under which a Galvanic Cell works

- Half-cells must be connected by a wire to allow electron flow from one to the other.
- Half-cells must be connected by a "salt-bridge" (explanation next page)
- Electrodes must be 2 different metals.
- Electrodes must dip into an "electrolyte" solution containing ions.

Which Electrode is Which?

You will quickly find that if you connect the voltmeter the wrong way around, that the needle deflects backwards.

To make it read correctly, the more active metal is always connected to the negative connection.

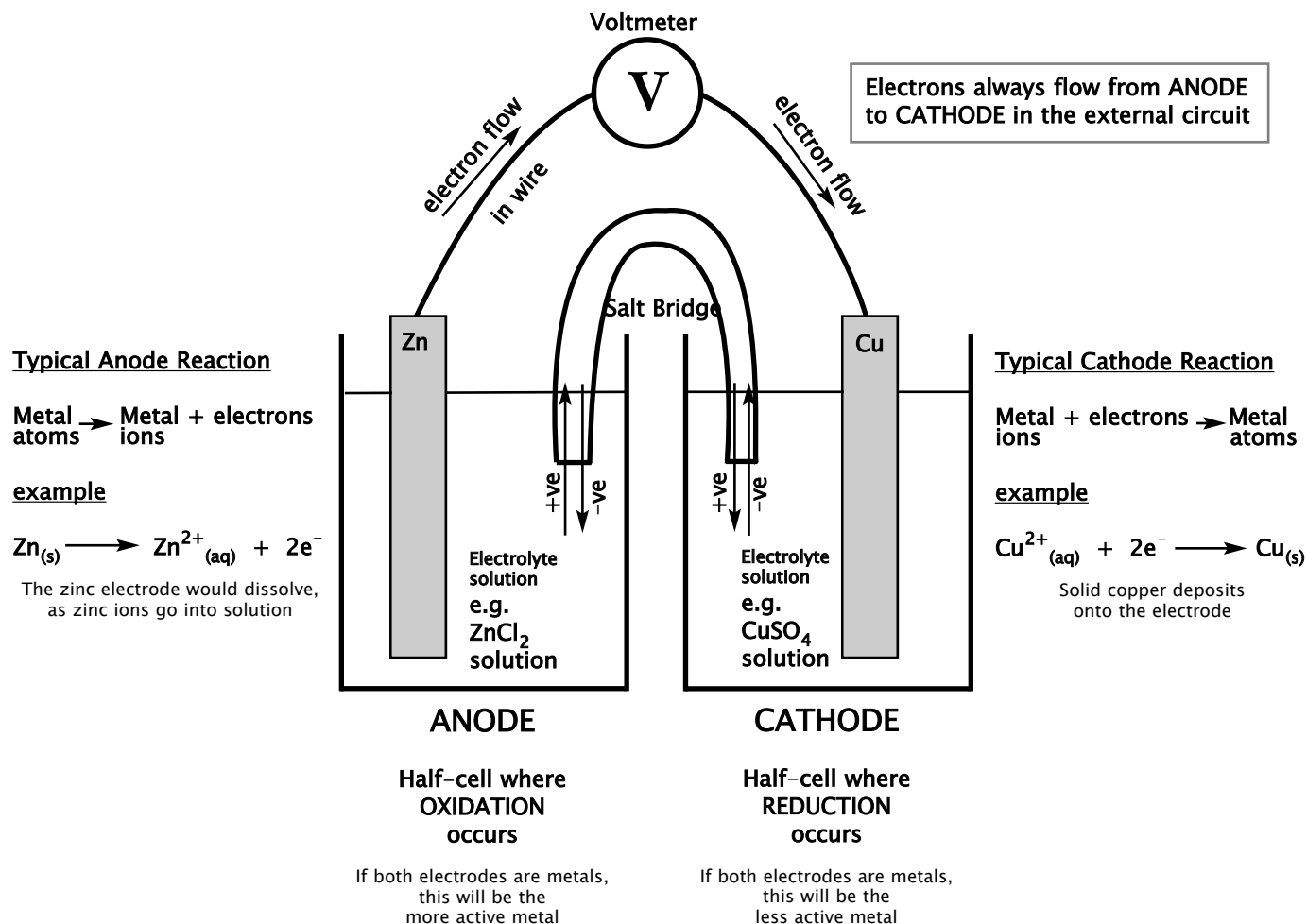
This is because the more active metal always oxidizes (loses electrons). Therefore, electrons flow from the more active metal.

The Size of the Potential Difference

If you test various combinations of metals (but always use the same concentration of solutions) you will find that...

...the further apart the metals are in the Activity Series, the higher the cell voltage (potential difference).

A Typical Galvanic Cell



Definitions & Things To Know...

The **Salt Bridge** can be just a filter paper soaked in electrolyte, or a tube of electrolyte jelly, or even just the electrolyte solution itself. It must allow diffusion of ions from one half-cell to the other

Ions migrate through the Salt Bridge to keep the total charge in each half-cell neutral

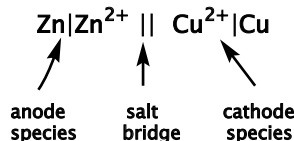
An "**Electrolyte**" is a substance which will conduct electricity when molten, or in solution.

Generally, it refers to ionic solutions

An "**Electrode**" is a conductor placed in each half-cell to pick up or release electrons.

Sometimes the electrode is involved in the reaction; in other cases it can be "inert".

Each cell can be described by a "short-hand". The cell above would be described by



Spectator Ions

Be aware that there must be other ions in the solutions as well. For example, the solutions shown contain Cl^{-} and SO_4^{2-} ions as well as the metal ions. They take no part, except to migrate through the Salt Bridge.

Standard Electrode Potentials

The actual voltage reading you get when you set up an electrochemical cell depends on many factors:

- the metals used at the electrodes (in particular, how far apart the 2 metals are in the Activity Series)
- the concentration of electrolyte solutions
- the temperature
- the gas pressure, if any gases are involved

Therefore, to make comparisons and predictions, it is necessary to specify a set of standard conditions for measuring the voltage of any cell.

The standard conditions are (predictably)

- all solutions are 1.0 mol L^{-1}
- temperature and gas pressure at SLC (25°C & 1 atm)

Under these conditions, each half-cell has a “Standard Electrode Potential” when measured against a “Reference Half-Cell”. The reference used is the reaction



This half-cell has been assigned a Standard Electrode Potential (E°) of zero volts, and all other half-cells are measured from this.

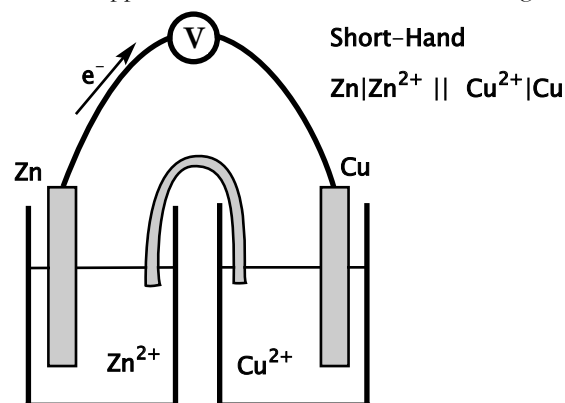
You may have been given a “Chemistry Data Sheet” containing a list of standard electrode potentials. Here is a shorter version for quick reference, which will be used throughout these notes and exercises.

Some Standard Potentials	E° (V)
$\text{Ca}^{2+} + 2\text{e}^- \rightleftharpoons \text{Ca}_{(\text{s})}$	-2.87
$\text{Mg}^{2+} + 2\text{e}^- \rightleftharpoons \text{Mg}_{(\text{s})}$	-2.36
$\text{Zn}^{2+} + 2\text{e}^- \rightleftharpoons \text{Zn}_{(\text{s})}$	-0.76
$\text{Fe}^{2+} + 2\text{e}^- \rightleftharpoons \text{Fe}_{(\text{s})}$	-0.44
$2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{H}_{2(\text{g})}$	0.00
$\text{Cu}^{2+} + 2\text{e}^- \rightleftharpoons \text{Cu}_{(\text{s})}$	+0.34
$\text{I}_{2(\text{aq})} + 2\text{e}^- \rightleftharpoons 2\text{I}^-_{(\text{aq})}$	+0.62
$\text{Fe}^{3+} + \text{e}^- \rightleftharpoons \text{Fe}^{2+}_{(\text{s})}$	+0.77
$\text{O}_{2(\text{g})} + 4\text{H}^+_{(\text{aq})} + 4\text{e}^- \rightleftharpoons 2\text{H}_2\text{O}_{(\text{l})}$	+1.23
$\text{Cl}_{2(\text{aq})} + 2\text{e}^- \rightleftharpoons 2\text{Cl}^-_{(\text{aq})}$	+1.36

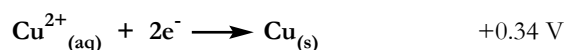
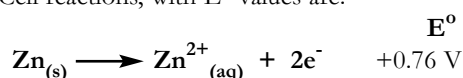
Notice that each half-equation is written as a reduction. If you need to write it backwards as an oxidation, then simply reverse the sign of the E° value.

Using Electrochemical Data

Consider the cell described previously, which contained zinc and copper electrodes in solutions of matching ions.



The Half-Cell reactions, with E° values are:



$$\text{Total Cell Voltage} = \underline{\underline{+1.10 \text{ V}}}$$

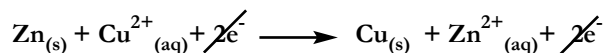
This means that, under standard conditions, this cell will produce a voltage (technically, an “Electromotive Force” (EMF), or “Potential Difference”) of 1.10 volts.

Notes:

1. The zinc reaction was written as an oxidation, the reverse of the half-cell equation given in the table at left. Since the equation was reversed, the sign of the E° value was reversed also.

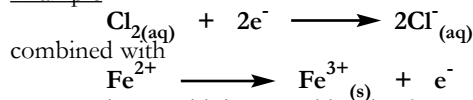
2. The total cell voltage is simply the sum of the half-cell E° values.

3. The overall equation for the reaction can be found by simply adding together the 2 half-equations, being sure that the same number of electrons are on each side and therefore, “cancel-out” as follows:

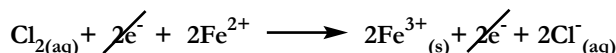


Any 2 half-equations can be combined this way, but sometimes it may be necessary to multiply one or both by a factor so that the electrons will cancel.

Example:



You need to multiply everything in the 2nd equation x2 before combining them



However, when you do this, the E° values DO NOT CHANGE

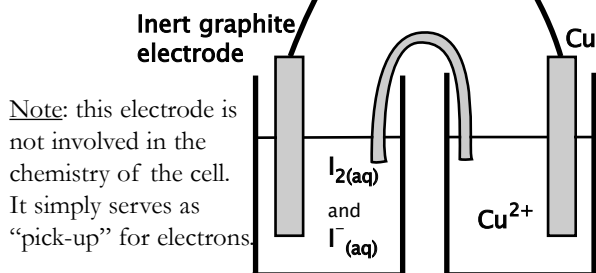
Using Electrochemical Data (continued)

So, how do you know which half-equation to reverse and write as an oxidation?

Simple!

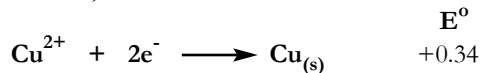
In all "Galvanic Cells" the sum of the E° values must be a positive voltage. **THE HALF-EQUATION HIGHER UP THE "STANDARD POTENTIALS" TABLE MUST ALWAYS BE REVERSED AND WRITTEN AS AN OXIDATION.**

Study this example:



Note: this electrode is not involved in the chemistry of the cell. It simply serves as "pick-up" for electrons.

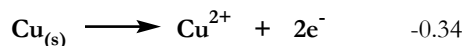
From the table, the half-cell reactions involved must be:



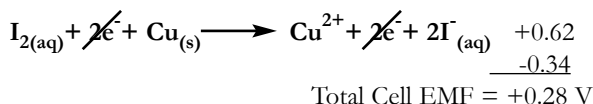
and



The copper equation is higher up the Standard Potentials table, so it must run in reverse as an oxidation. Don't forget to reverse the sign of the E° value too.

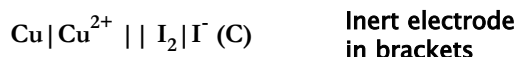


Now combine the half-equations to form the overall equation, and add the E° 's to get the total cell EMF.



In the diagram above, the Copper half-cell is the ANODE (oxidation) and the Iodine half-cell is the CATHODE (reduction). Electrons would flow from the copper electrode towards the graphite (carbon) electrode.

The "Shorthand" description for this cell is:



Notes

1. There would also be "spectator ions" in each half-cell. They have been totally ignored above.

2. Inert electrodes are used whenever a metal is not involved in one of the half-reactions. Compressed graphite (carbon) is commonly used. Platinum (Pt) is the best, but very expensive.

Oxidation States & Numbers

We use a simple number system to describe the "oxidation state" of any chemical species.

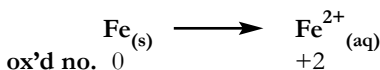
- neutral elements, in their normal state, have oxidation number = zero
- simple ions, oxidation number = charge on ion

Examples:	Species	Oxidation number
iron atom	$\text{Fe}_{(s)}$	0
iron(II) ion	$\text{Fe}^{2+}_{(aq)}$	+2
iron(III) ion	$\text{Fe}^{3+}_{(aq)}$	+3
chloride ion	$\text{Cl}^-_{(aq)}$	-1
chlorine molecule	$\text{Cl}_{2(aq)} \text{ or } (\text{g})$	0

If, during a REDOX reaction the oxidation number of a species **increases**, then it has been **OXIDIZED**.

If, during a REDOX reaction the oxidation number of a species **decreases**, then it has been **REDUCED**.

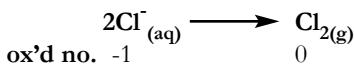
Examples of Half-Equations with Oxidation Numbers



ox'd no. 0

+2

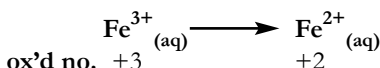
Ox'd number has increased, \therefore Oxidation has occurred.



ox'd no. -1

0

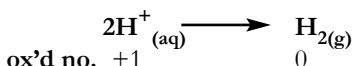
Ox'd number has increased, \therefore Oxidation has occurred.



ox'd no. +3

+2

Ox'd number has decreased, \therefore Reduction has occurred.

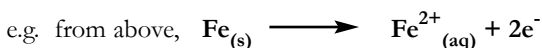


ox'd no. +1

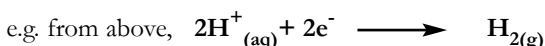
0

Ox'd number has decreased, \therefore Reduction has occurred.

Wherever an oxidation has occurred, electrons have been lost. If you add electron(s) to the RIGHT side of the half-equation, the charges will balance.



For reductions, add electron(s) to the LEFT side.

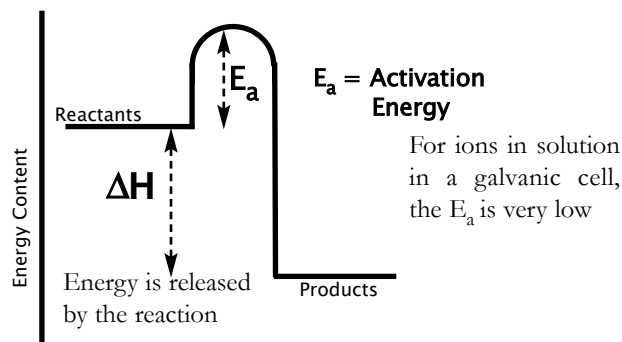


Try the WORKSHEET at the end of section

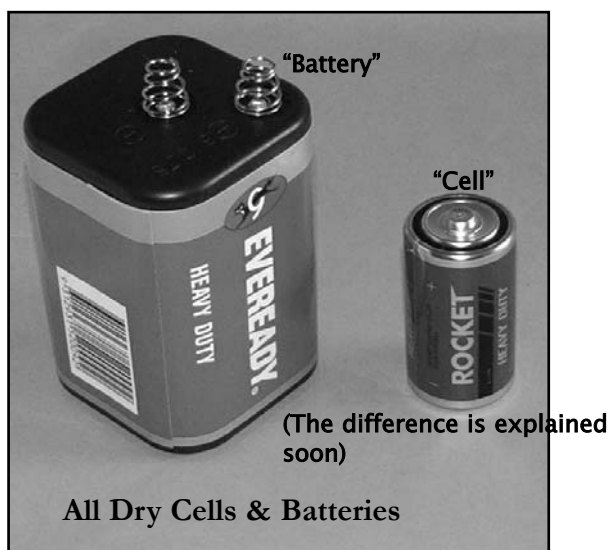
More on Galvanic Cells (Optional)

Galvanic Cells are those which run spontaneously, and produce energy, in the form of electricity.

This means that the reactions involved are **Exothermic**.



The size of ΔH in the energy profile is related to the cell EMF (voltage) produced by a Galvanic Cell. Confusingly, for exothermic reactions ΔH is defined to be negative, while the cell voltage must be positive. This is entirely due to the definitions involved, and is not really a contradiction.

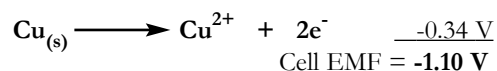
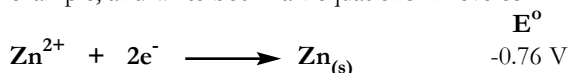


are Galvanic Cells...
...spontaneous, Exothermic,
with positive cell voltage



What if the Cell Voltage is Negative?

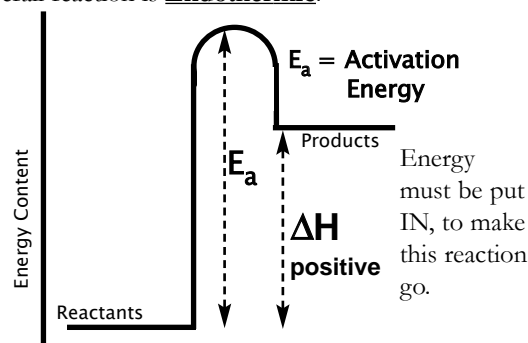
Lets take the same cell that has previously been used as the example, and write both half-equations in reverse:



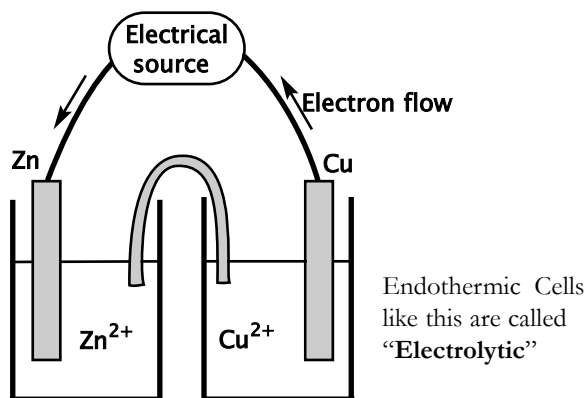
What does this mean?

The cell is NOT "Galvanic". It will NOT run spontaneously. Instead of producing electricity, you would have to put electricity INTO the cell (minimum 1.10 Volts) to make these reactions run.

The overall reaction is **Endothermic**.



To make this cell, you could use exactly the same half-cells, but instead of connecting a voltmeter in the circuit, you would need to place an electrical source, such as a battery or "power pack" to provide energy.



Notice that all the half-equations in the "Standard Potentials" table are shown with double arrows. \rightleftharpoons
This is to indicate that each reaction is reversible, and can run in either direction, depending on the energy situation.

The material on this page is NOT required learning according to the Syllabus.
It has been included in the interests of better understanding.

Cells & Batteries

Firstly, what's the difference?

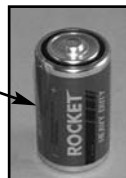
A cell is an electrochemical unit with just one anode and one cathode. A "battery" is 2 or more cells linked together to provide more power. When you place 2 or more cells into a flashlight you are making a battery. A car battery is made of six cells connected together. Each cell provides 2 volts, and the entire battery gives 12 volts.

In everyday usage, this is called a "battery", but in fact it is a cell.



This "battery" really is a battery. Inside are 4 connected cells, each 1.5 volts.

The entire device gives 6 volts.

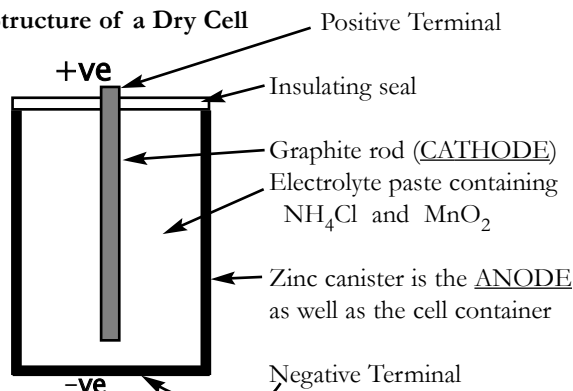


The "Ordinary" Dry Cell (Leclanche Cell)

The original cells and batteries were all "wet cells", in that they contained liquid solutions which had to be kept upright and tended to be large, messy and not easily transported. A vital use was the Morse Code Telegraph.

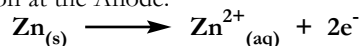
The first "dry cell" was invented by Leclanche in 1866, and developed to commercial standard by Gassner in 1881. The electrolyte solution is a thick "paste", and the entire cell is sealed against spillage, and easily transported.

Structure of a Dry Cell

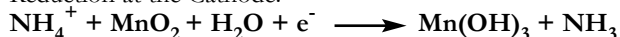


Chemistry of the Leclanche Cell

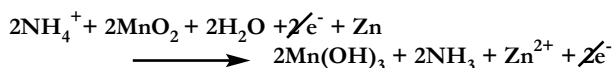
Oxidation at the Anode:



Reduction at the Cathode:



To get the overall cell reaction, you need to firstly multiply the cathode equation x2, so the electrons will cancel.



Cost, Practicality and Impact on Society

The standard dry cell is very cheap to produce, and can be made in a variety of sizes so it is very practical as a power source for flashlights, remote controls, portable radios, many toys, calculators, etc.

For more power, multi-cell batteries (photo at left) can be made to power larger flashlights or other devices.

In fact, the dry cell encouraged the development of all these devices. Small portable electrical devices would never have been invented if cells and batteries had not been available to power them.

Environmental Impact

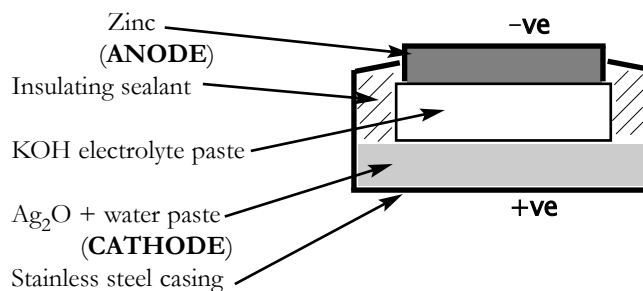
of this technology is minimal, since the chemicals involved do not cause any significant problems when disposed of into landfill rubbish dumps.

The Silver Oxide "Button Cell"

There is a limit to how small you can make a standard dry cell and still get a practical amount of electricity from it.

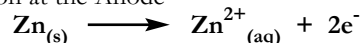
The development of really small electrical devices such as hearing aids, digital watches and remote-locking devices for cars, was made possible by the invention of the "Button Cell".

Structure

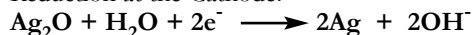


Chemistry

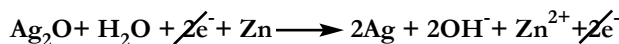
Oxidation at the Anode



Reduction at the Cathode:



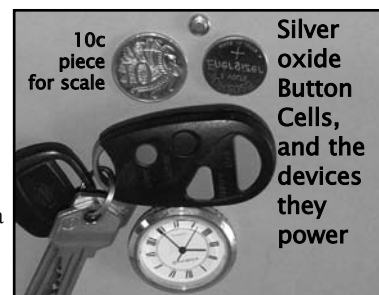
So, overall reaction is:



Button Cells are relatively expensive, but last a long time in miniature, low-energy devices. Their tiny size and good performance are worth the expense.

Environmental Impact

is low because these cells contain so little material, and the relatively inert stainless steel and silver metal inside them is not a significant environmental hazard.



Worksheet 3

Part A Fill in the Blank Spaces

The “a)..... Series” of Metals controls what happens when a metal reacts with the b)..... of another metal in solution. If the metal is c)..... the Series, it will d)..... the lower-activity ion from the solution. In this process, the atoms of the higher-activity metal e)..... electrons, and become ions in the solution. The process of losing electrons is called “f).....” Meanwhile, the ions of the less-active metal g)..... electrons and form atoms, which form a solid precipitate. The process of gaining electrons is called h).....

Neither process can occur alone; each can only happen with the other, so the entire reaction is called i)..... or simply “j).....”

Although oxidation and reduction must occur together, they can be separated as long as k)..... can flow from the site of l)..... to the site of m)..... through a wire. This is the basis of all electrical n)..... and

A typical electric cell consists of 2 o)..... In one, called the p)....., oxidation occurs, while reduction occurs in the q)..... half-cell. The 2 half-cells must be connected by a conducting circuit so that r)..... can flow from the s)..... to the t)..... Half-cells must also be connected by a “u)..... Bridge” to allow v)..... to diffuse between half-cells, so that the total w)..... remains balanced.

The voltage (or x).....) of a cell can be determined from a table of “y)..... Potentials”. Each half-reaction has been measured (under z)..... conditions) against a “reference half-cell”. The reference used is the aa)..... half-reaction which has been given a value of ab)..... volts, and all other half-cells measured against it.

For Galvanic Cells, when combining any 2 half-equations from the table, the one ac)..... the table must always be written as an ad)....., and its E° value ae)..... You can then af)..... the 2 E° values to get the total cell ag)..... under standard conditions.

**WHEN COMPLETED, WORKSHEETS
BECOME SECTION SUMMARIES**

A Galvanic Cell is one which has a ah)..... cell EMF and will run ai)..... when connected. The chemical reaction is aj).....-thermic.

The original “ak)..... cell” allowed the invention and development of many small, portable, electrical devices. “al)..... cells” have allowed even further miniaturization.

Part B Practice problems

1. Metal Displacement Reactions

For each combination below, firstly use the “Activity Series” to decide whether or not a reaction would occur.

If not, write “no reaction”. If so,

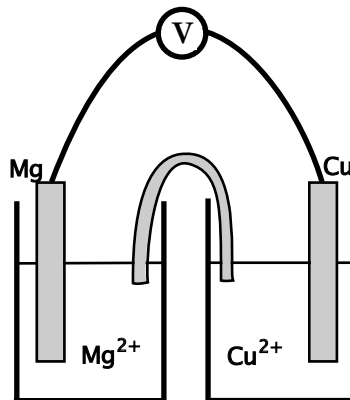
- write half-equations for the change occurring to each species. Label each half-reaction as “oxidn.” or “reduction”
- write a balanced, net ionic equation for the overall reaction.

- Magnesium metal placed in a solution of Pb^{2+} ions.
- Lead metal placed in a solution of Mg^{2+} ions.
- Aluminium metal placed in a solution of Cu^{2+} ions.
- Copper metal placed in a solution of Ag^+ ions.
- Iron metal placed in a solution of Ba^{2+} ions.
- Calcium metal placed in a solution of Sn^{2+} ions.

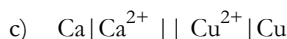
2. Galvanic Cells

For each cell diagram or description, below:

- Write half-equations for each half-cell. Label each as “Anode reaction” or “Cathode reaction”
 - Find the cell EMF under standard conditions.
 - Write an overall, balanced, net ionic equation for the cell
- a)

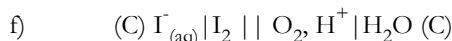


- b) One half cell comprises an iron electrode in a solution of Fe^{2+} ions. The other has a magnesium electrode in Mg^{2+}



- d) An inert graphite electrode is in contact with an acid (contains H^+) in a stream of $\text{H}_{2(g)}$. This is connected to a $\text{Zn} / \text{Zn}^{2+}$ half-cell.

- e) The same H^+ / H_2 half cell is connected to one containing a graphite electrode in a solution containing Cl^- ions, and dissolved $\text{Cl}_{2(aq)}$



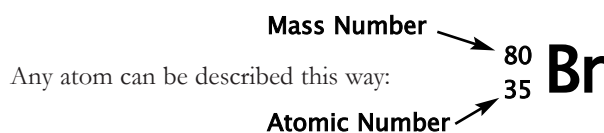
4. RADIOACTIVITY & ITS USES

Atomic Mass Number and “Atomic Weight”

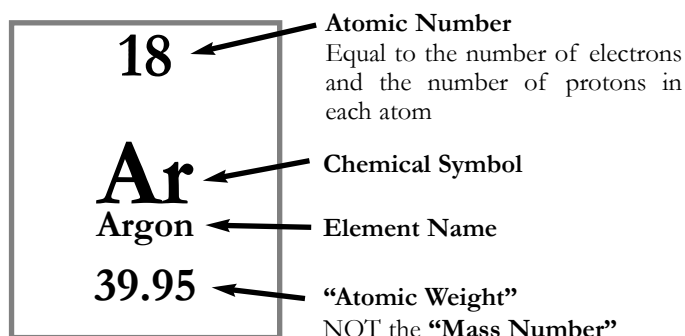
You should recall that the mass of an atom:

$$\text{Mass Number} = \text{sum of (protons + neutrons)}$$

The mass number is always a whole number.



However, on the Periodic Table, elements are described like this:



... and the “Atomic Weight” is usually NOT a whole number. Now (finally) the explanation:

Isotopes

You already know that each element is composed of atoms which are all the same as each other. Well, that’s almost true!

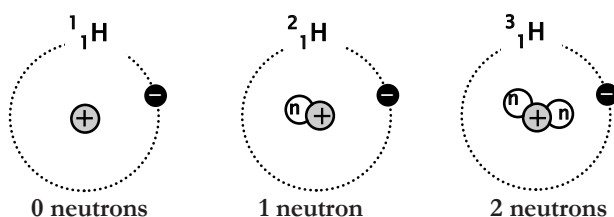
All the atoms of an element have exactly the same

- number of protons
 - number of electrons
- } = **“Atomic Number”**

It is the number of electrons, and their arrangement in their orbits which gives each atom its chemical properties, and defines it as a particular element.

However, the number of neutrons can vary:

Example: the Isotopes of Hydrogen



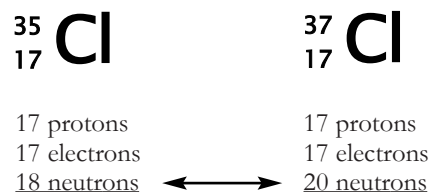
These atoms all have the same chemistry, because the electrons are the same in each; so they are all Hydrogen. However, their **Mass Numbers** are different.

ISOTOPES

are atoms of the same element
(same Atomic Number)
but with different numbers of neutrons
and different **MASS NUMBERS**

Most elements exist in nature as a mixture of 2 or more isotopes. The **“Atomic Mass”** shown on the Periodic Table is the weighted average of the mixture of isotopes that occurs on Earth.

Example: Chlorine exists as 2 isotopes:



On Earth, there is a mixture of these 2 isotopes in such a proportion so that the “average” atomic mass is 35.45. This is the value of Atomic Weight shown in the Periodic Table.

Isotopes are commonly described by their individual mass numbers. The isotopes above are called **“Chlorine-35”** and **“Chlorine-37”**, or simply **Cl-35** and **Cl-37**.

Below left are Hydrogen-1, Hydrogen-2 and Hydrogen-3.

Radioactivity

In 1896, the French scientist Henri Becquerel discovered that certain minerals, containing uranium, were emitting a mysterious, invisible radiation.

It was then discovered that there were, in fact, 3 different radiations that were soon called **alpha (α)**, **beta (β)** and **gamma (γ)** rays, and that these were coming from the nucleus of atoms.

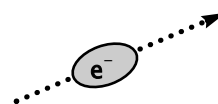
Alpha Radiation

is a stream of particles. An alpha particle is a “chunk” of nucleus, made up of 2 protons and 2 neutrons.



Beta Radiation

is also a stream of particles, this time high-speed electrons ejected from an atomic nucleus.



Gamma Radiation

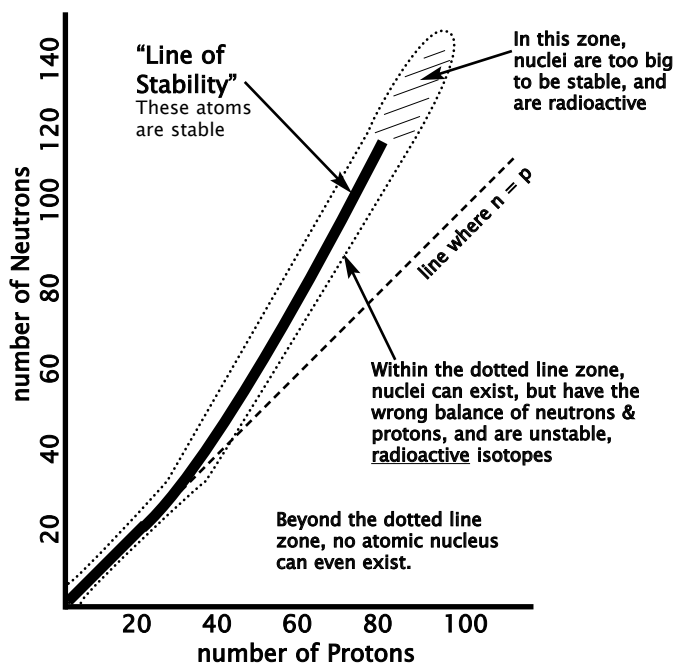
is very high frequency electromagnetic waves, similar to X-rays, but carrying even more energy. Gamma radiation is often associated with the emission of alpha and beta particles.



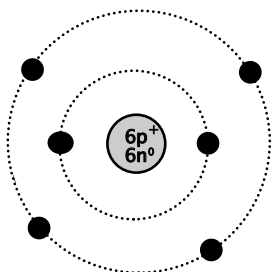
Radioactivity and Nuclear Stability

It turns out that you can't have any old combination of protons and neutrons in an atomic nucleus... the nucleus can only be stable if the proton-neutron ratio is within certain, very narrow limits.

This is best seen if all the known isotopes of all the elements are plotted on a graph, as follows.



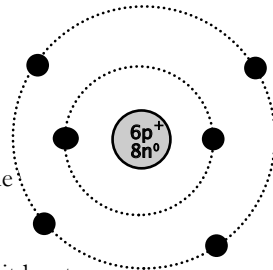
As an example, consider the isotopes of carbon:



¹²₆C
Carbon-12, if plotted on the graph, lies exactly on the "Line of Stability"



Carbon-14 lies just above the "Line of Stability", inside the "dotted-line zone".



The nucleus is unstable because it has too many neutrons, (or not enough protons) in its neutron:proton ratio.

To achieve stability, it undergoes a **Radioactive Decay** to get rid of some electric charge and some energy.

In the case of Carbon-14, it emits a Beta particle and Gamma energy and transmutes into a stable nitrogen atom. (Details are NOT required by the Syllabus)

Transuranic Elements

As the graph shows, once a nucleus has more than about 80 protons (and about 120 neutrons) it becomes too large to be fully stable. There are naturally occurring elements with larger nuclei, but they are all unstable and radioactive.

The largest naturally occurring atoms are isotopes of uranium (Atomic Number 92), and in early text books you will see that the Periodic Table ended at uranium. However, over the past 50 years or so, it has become possible to artificially manufacture atoms of elements larger than uranium. These are called the "Transuranic Elements".

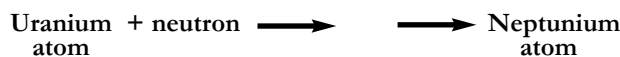
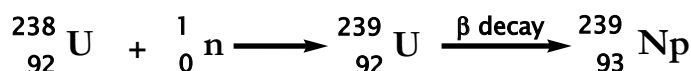
Most Periodic Tables now list transuranic elements as far as Atomic Number 110 or even to No.118, although the names for some of these have not been agreed upon, and in some cases only tiny quantities have ever been made, and they are so unstable that their existence is fleeting.

Making Transuranic Atoms

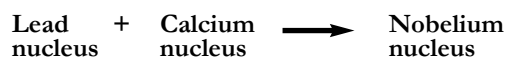
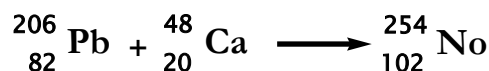
The elements immediately after uranium can be made in relatively large quantities in a nuclear reactor, by a process of neutron bombardment.

Example:

If the isotope uranium-238 is placed in a nuclear reactor, it will be bombarded by neutrons (released by the nuclear fission occurring in the reactor). A neutron will eventually strike the nucleus and cause the following nuclear reactions:



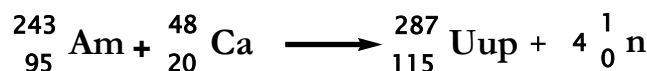
Beyond element number 95, it is only possible to make small numbers of new atoms in a Particle Accelerator. Atomic nuclei are accelerated up to very high speeds by powerful magnetic fields, and then collided so that sometimes 2 nuclei will fuse together, such as:



Recent Discoveries

A 1999 claim for the production of element 118 has not been confirmed by other scientists.

In 2004, a few atoms of element 115 (temporarily named Ununpentium) were apparently made by the reaction:



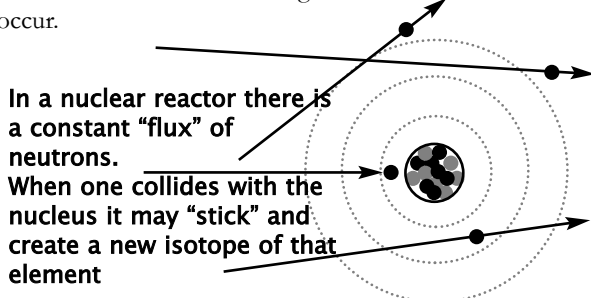
Commercial Radioisotopes

Although making a few atoms of a new Transuranic element might capture the scientific headlines, the important routine job of making useful, radioactive materials goes on every day.

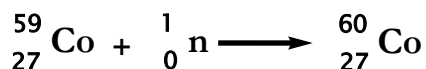
Australia is a non-nuclear country, but we do have one small nuclear reactor at Lucas Heights in Sydney. Its purpose is research, and to prepare useful radioisotopes for medical and industrial use.

Production of Commercial Radioisotopes

Generally, the production of useful radioactive materials is achieved by placing the appropriate “target” atoms inside a nuclear reactor and allowing neutron bombardment to occur.

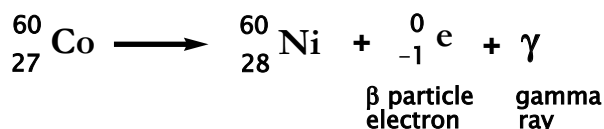


One of the most important and commonly used radioisotopes produced is Cobalt-60. It is produced when “ordinary”, stable Cobalt-59 absorbs a neutron:



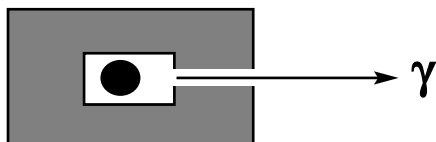
Uses of Radioisotopes

Cobalt-60 is unstable and undergoes Beta Decay:



It is the gamma radiation which makes Cobalt-60 very useful in a variety of roles in both medicine and industry.

By enclosing the radioactive material inside a heavily shielded container with a narrow aperture, a narrow beam of gamma rays can be produced.

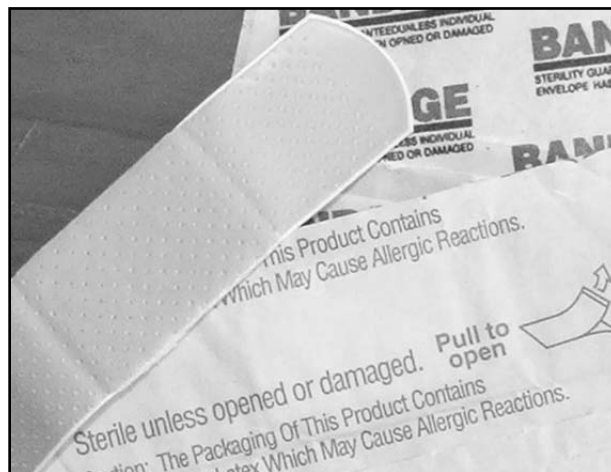


The energy carried by gamma rays can vary considerably. The radiation from Cobalt-60 is ideal for certain industrial applications and in the medical treatment of some cancers.

Industrial Uses of Cobalt-60

The gamma rays from Cobalt-60 are very penetrating, and very destructive to living cells.

In the production of medical supplies, such as bandages and dressings, it is vital that the product is totally sterile (germ-free). This is achieved by irradiating the products with doses of gamma radiation high enough to destroy any bacteria or fungi spores which might be present.



In aircraft manufacture, the airplane parts may be welded together. It is essential that the welded joints are totally strong and free of defects. (Having a wing fall off in flight is not a good look this season!) To “see” inside the weld, gamma rays are used like X-rays; they are beamed through the welded joint and an image captured by a “gamma-ray camera”. Analysis of the image allows engineers to be sure of the quality of the welding.

Medical Uses of Cobalt-60

Some forms of cancer can be treated by beaming the gamma rays into the tumour. Cancer cells are actively growing and this makes their DNA more susceptible to gamma ray damage than healthy cells.

By focusing the beam into the tumour, and using carefully controlled doses of radiation, it is possible to destroy cancer cells with minimal damage to healthy tissue.

Why is Cobalt-60 Ideal for These Uses?

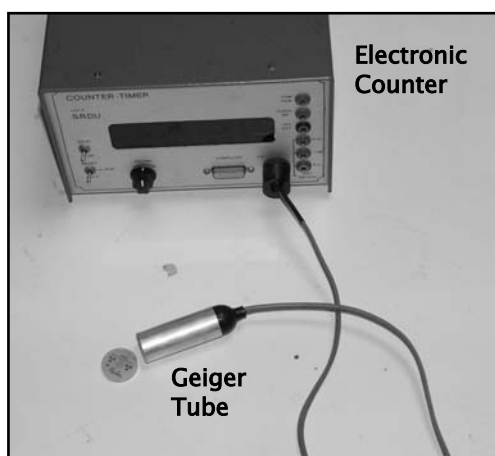
- Cobalt-60 has a half-life of 5.3 years, so once a cannister is prepared, it will have a useful life of about 6-10 years before it needs to be replaced. This is convenient for industrial and medical uses.
- The energy of the gamma rays emitted by Cobalt-60 is ideal for the imaging of welded metal joints, and for killing living cells, whether tumour cells or bacteria on a bandage.
- It is relatively cheap and easy to prepare Cobalt-60 by inserting “ordinary” Cobalt-59 into a nuclear reactor and allowing neutron-bombardment to occur.

Detection of Radiation

The Alpha, Beta and Gamma radiations from radioisotopes can be detected in various ways.

- Photographic Film is “exposed” by these radiations, and can be used to detect it. (This was how radioactivity was first discovered.)
- The “Geiger-Counter”, or Geiger-Muller Tube is an electronic device which detects radiation because of the ionization it causes.

Radiation causes electrons to be knocked out of their orbits, so the atom becomes an ion. One alpha particle can ionize thousands of atoms, causing a tube of non-conducting gas (Argon is often used) to become momentarily conductive.



An electronic circuit detects the change and “counts” the ionization events occurring when radiation is present.

- A Scintillation Counter detects radiation by the flash of light which some chemicals emit when struck by radiation. Light-sensitive detectors pick up each tiny flash of light and an electronic circuit counts and records the events.

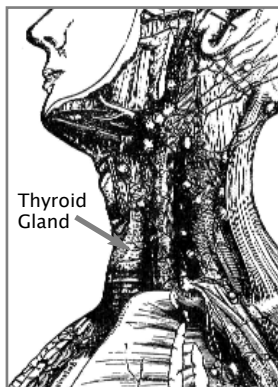
Use of a Radioisotope Related to Chemistry

The syllabus requires that you are able to explain the use of radioisotopes in terms of their chemical properties.

A good example is the use of Iodine-131 in the medical treatment of thyroid cancer. The thyroid gland is located in the throat, and produces a vital hormone which has iodine atoms in it.

This gland is the only part of the body which uses iodine, and enzymes in the gland are able to chemically “recognize” iodine ions and very efficiently “harvest” iodine from the blood stream.

Iodine-131 is radioactive and emits beta and gamma rays.



If a small amount of I-131 is injected into a patient who has a tumour in the thyroid gland, the radiation level is so low that there is little risk to their healthy tissue.

However, due to the chemistry of the iodine, the thyroid gland rapidly absorbs the isotope and concentrates it. The radiation is concentrated in the “target organ” and is very effective in destroying the tumour.

I-131 has a short half-life and the radiation disappears rapidly.

Benefits and Problems

of the Use of Radioisotopes

Some practical uses of radioisotopes were described on the previous page.

Benefits

- Using gamma rays to check the quality of a welded joint is the only way to ensure quality, without breaking the joint open to inspect it visually. X-rays will not penetrate the metal well enough; only the penetrating nature of the gamma rays makes this possible.

The benefits to air safety should be obvious.

- Using gamma rays to sterilize bandages is cheaper and more effective and reliable than the alternatives which include heat treatments and/or chemical antiseptics.

- The use of gamma ray therapy for certain cancers is sometimes the best option in cases where surgery and/or chemotherapy are not appropriate. Medical professionals have found that there are positive benefits in terms of treating the disease.

Problems

The problems associated with the use of radioisotopes, centre mainly around the safety of the people who work with the radioactive materials.

All radiations are dangerous to living cells, and even low-level exposure is known to increase the risk of genetic mutations and development of cancers.

From the workers at the nuclear reactor, to those who handle and transport the isotopes, to the professional end-users in hospitals or industry, there are risks of dangerous exposure to radiation.

The key to safety is effective packaging and shielding of the material, and constant monitoring for escaped radiation. For example, all personnel in “at-risk” jobs and environments must wear small “tell-tale” detectors to warn of radiation exposure.

Worksheet 4

Fill in the blanks

Isotopes are atoms of the same a)..... which have the same atomic b)....., but different c)..... because they have a different number of d)..... in the nucleus. Most elements occur in nature as a mixture of 2 or more e).....

The “Atomic Weight” shown on the periodic table is the “weighted f).....” of the masses of the mix of isotopes in nature.

Isotopes of an element show exactly the same g)..... properties, but some may be unstable and h)..... There are 3 different radiations that might be emitted:

- i)..... (α) radiation is a stream of particles. Each particle is composed of j)..... and
- Beta radiation (symbol, k).....) is a stream of l).....
- m)..... (γ) radiation is n).....-frequency waves.

Whether or not any isotope is stable or radioactive is mainly determined by the ratio of o)..... to in the nucleus, and also how large the nucleus is. All atoms with more than about p)..... protons are too big to be stable.

The largest naturally-occurring atoms are of the element q)..... which has atomic number r)..... Atoms larger than this are called “s)..... Elements” and are all made artificially by either t)..... - bombardment in a nuclear reactor, or by colliding different nuclei in a u).....

Commercial Radioisotopes can also be prepared by neutron- v)..... in a w)..... One of the most commonly used radioisotopes is Cobalt-x)....., which is unstable and decays by emitting y)..... and rays.

It is used in industry for z)..... medical bandages and dressings, and for checking the quality of aa)..... in aircraft manufacture. In medicine, it is used to treat ab)..... by killing the tumour cells with ac)..... rays.

The radiations from radioactive substances can be detected and measured by ad)..... film, as well as the “ae).....-Counter” which electronically registers the af)..... effects of radiation. Another method of detection, called a “ag).....-Counter”, detects the ah)..... which some chemicals emit when struck by radiations.

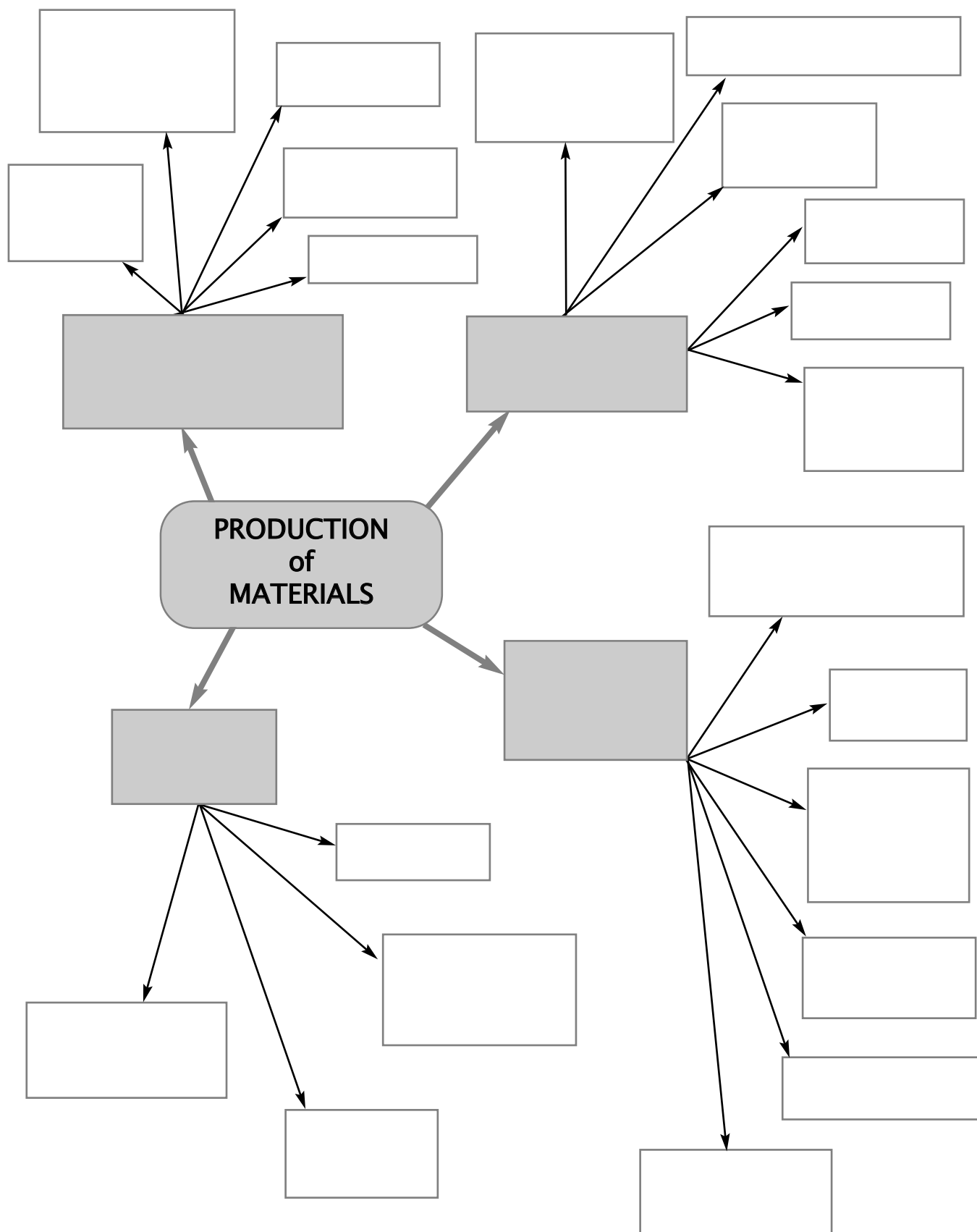
The benefits of using radioisotopes are related to each specific use. The problems associated with radioactive materials are mainly linked to the ai)..... of personnel who work with them.

**WHEN COMPLETED, WORKSHEETS
BECOME SECTION SUMMARIES**

CONCEPT DIAGRAM ("Mind Map") OF TOPIC

Some students find that memorizing the OUTLINE of a topic helps them learn and remember the concepts and important facts.

Practise on this blank version.



Practice Questions

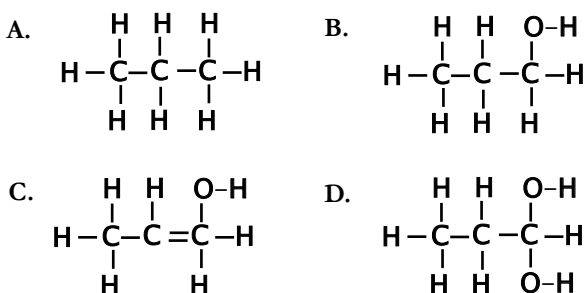
These are not intended to be "HSC style" questions, but to challenge your basic knowledge and understanding of the topic, and remind you of what you NEED to know at the K.I.S.S. Principle level.

When you have confidently mastered this level, it is strongly recommended you work on questions from past exam papers.

Part A Multiple Choice

1.

If propene (C_3H_6) underwent an addition reaction with water, the correct structural formula for the product would be



2.

Alkenes can be identified by their reaction with bromine water, in which the bromine:

- A. moves from one liquid layer to the other.
- B. changes colour from brown to purple.
- C. completely loses its colour.
- D. changes from colourless to purple.

3.

In the "Catalytic Cracking" of the alkane $C_{20}H_{42}$, the molecule happened to break up into 4 pieces; 1 molecule of ethylene, one of octane, 1 of hexene, and another hydrocarbon molecule. The formula for the 4th fragment would be:

- A. C_4H_8 B. C_6H_{12} C. C_2H_4 D. C_3H_8

4.

An "addition polymer" is formed when:

- A. long-chain alkane molecules combine.
- B. $C=C$ double bonds are formed in monomer molecules.
- C. molecules join by removing atoms to create bonds.
- D. monomers join by splitting $C=C$ double bonds.

5.

In general terms, increasing the size and mass of any "side groups" in an ethylene-based plastic, will probably result in the plastic being

- A. softer and more flexible.
- B. less soluble in water.
- C. a better conductor of electricity.
- D. harder and more rigid.

6.

Cellulose is:

- A. an addition polymer of ethylene.
- B. a condensation polymer of glucose.
- C. an addition polymer of glucose.
- D. a monomer which can be polymerized.

7.

Theoretically, we should be able to use cellulose as a raw material to replace petroleum compounds. However, there is one technology lacking which prevents this becoming an economically viable process. The step missing is a cheap efficient way to convert:

- A. cellulose into glucose.
- B. glucose into ethanol.
- C. ethanol into ethylene.
- D. ethylene into plastics.

8.

The alkanol with condensed structural formula $CH_3(CH_2)_4CH_2OH$ would be called:

- A. butanol B. pentanol C. hexanol D. heptanol

9.

The alkanols have much higher m.p.'s & b.p.'s compared to the corresponding alkanes, because:

- A. the mass of the OH group increases dispersion forces.
- B. the intra-molecular covalent bonds are stronger.
- C. the O-H bond is polar, creating a dipole.
- D. the $C=C$ double bond is much stronger than C-C bonds.

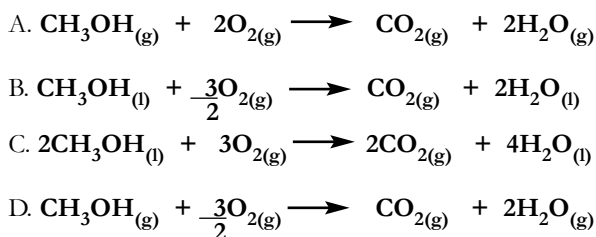
10.

As well as a source of carbohydrates and some live yeast, the other necessary conditions for the production of ethanol by fermentation are:

- A. temperature above 40°C and plenty of oxygen.
- B. anaerobic conditions and temperature below 20°C .
- C. temperature around 25°C and plenty of oxygen.
- D. anaerobic conditions and temperatures about 25°C .

11.

Which equation for the combustion of methanol is the one for which the energy released would be equal to ΔH_c ?



12.

Which of the following is NOT a reason to consider ethanol as a fuel to replace petrol?

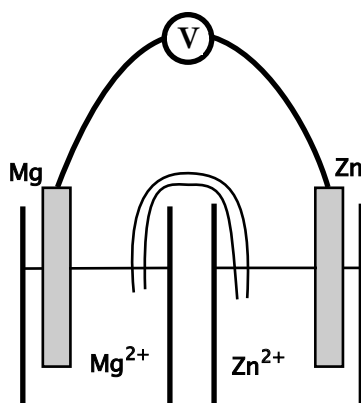
- A. Ethanol is a higher energy fuel than petrol.
- B. Ethanol is a renewable and sustainable resource.
- C. Ethanol is potentially "Greenhouse friendly".
- D. The technology to produce ethanol is already known.

13.

If each of the following metals were placed into a solution of copper(II) sulfate, which one would NOT react?

- A. silver
- B. zinc
- C. iron
- D. magnesium

14.



In the cell shown:

- A. electrons would flow towards the Mg half-cell.
- B. zinc would be oxidized by the reaction.
- C. positive ions would flow out of the Mg half-cell.
- D. the zinc half-cell is the anode.

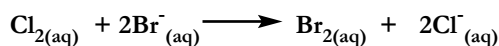
15.

The Galvanic Cell shown in Q14 uses a metal and ions of the same metal in each half-cell. If you built a series of similar cells, but used different metal combinations in each case, which of the following would give the highest cell voltage? (Assuming all other variables were kept the same.)

- A. iron & zinc
- B. copper and silver
- C. copper and magnesium
- D. magnesium and zinc

16.

In the following equation, which species has undergone reduction?



- A. $\text{Cl}_{2(\text{aq})}$
- B. $\text{Br}^{-}(\text{aq})$
- C. $\text{Br}_{2(\text{aq})}$
- D. $\text{Cl}^{-}(\text{aq})$

17.

Isotopes have

- A. the same mass number as each other.
- B. different atomic numbers.
- C. different electron configurations.
- D. the same chemical properties as each other.

18.

In order to manufacture atoms of Meitnerium (element number 109) a suitable method might be:

- A. neutron bombardment of uranium atoms.
- B. allow radioactive decay of element No.110.
- C. collision of lead & cobalt atoms in a particle accelerator.
- D. chemical addition reaction of uranium & chlorine.

Longer Response Questions

Mark values shown are suggestions only, and are to give you an idea of how detailed an answer is appropriate.

19. (3 marks)

Using structural formulas, show the addition reaction between ethylene and hydrogen bromide (HBr). Show the reactants and product(s). You do not need to name any compounds.

20. (4 marks)

Explain, using chemical equation(s) when needed, why liquid hexene will de-colourize a bromine solution, but liquid hexane will not.

21. (6 marks)

The main industrial source of ethylene is "Cat-Cracking" of certain molecules in petroleum.

- a) Outline the general process of "Cat-Cracking", including the meaning of the term.
- b) Outline the process of "Addition Polymerization" of ethylene.
- c) Draw a structural formula for a section of a polyethylene molecule containing 3 monomer units.

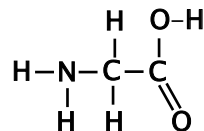
22. (7 marks)

A common plastic is known as P.V.C.

- a) Draw a structural formula for the monomer from which PVC is made, and give both its common name and systematic chemical name.
- b) Account for the differences in properties and typical uses of PVC compared to polyethylene.

23. (4 marks)

The amino acid "Glycine" has the following structure:



The condensation polymer "polyglycine" can be formed by joining together many glycine molecules.

- a) Use structural diagrams to show the 2 products formed when two glycine monomers join together.
- b) Explain why this is called "condensation" polymerization.

24. (9 marks)

- Describe the structure of the cellulose molecule, including the name of the monomer.
- Explain why cellulose can be considered a “renewable” resource.
- Write symbol equations (including catalysts) to summarize the reaction
 - of glucose to form ethanol.
 - of ethanol to form ethylene.

25. (5 marks)

- Describe in general terms, the differences in the properties of solubility in water, and m.p. & b.p., between the alkanes and the alkanols.

- Account for these differences in terms of the intra-molecular and inter-molecular bonds in each type.

26. (6 marks)

As part of your studies you have carried out an experiment to produce ethanol by fermentation.

- List the chemical substances placed in the reaction flask.
- Describe the conditions used to promote the reaction.
- List the significant observations made over several days of the reaction occurring.
- As part of the experiment, you will have monitored any mass change. State the result, and explain the change.
- What process was (or may have been) used to collect relatively pure ethanol.

27. (8 marks)

Using the equipment shown, the “Heat of Combustion” of methanol was measured experimentally.

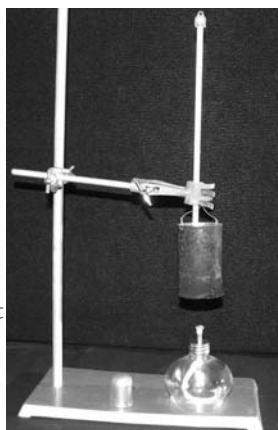
Results

- Mass of methanol burnt = 0.58g
- Mass of water in can = 100g
- Change in temperature of water in can = 14°C

- Write a balanced, symbol equation for the complete combustion of methanol.
- Calculate the amount of heat energy captured by the water in the can.

- Assuming 100% efficiency in this “calorimeter”, calculate the Heat of Combustion for methanol
 - per gram.
 - per mole.

- Explain why this value is unlikely to agree closely with the “text-book value”.



**FOR MAXIMUM MARKS SHOW
FORMULAS & WORKING,
APPROPRIATE PRECISION & UNITS
IN ALL CHEMICAL PROBLEMS**

28. (6 marks)

Assess the potential of ethanol as an alternative fuel, including discussion of the advantages and disadvantages of its use.

29. (10 marks)

- Write a net ionic equation for the reaction which occurs when a piece of magnesium metal is dropped into a solution of lead(II) nitrate.
- Write 2 separate “half-equations” for the reaction, and label each as either “oxidation” or “reduction”.
- Sketch a galvanic cell which could be set up (using simple laboratory equipment and appropriate chemicals) which would use the same reactions described in part (a) & (b). Label the “anode”, “cathode” and “salt bridge” and show the direction of electron flow in the external circuit.
- Determine the value of the cell voltage under standard conditions.

30. (6 marks)

Solid copper metal reacts with a solution containing molecular chlorine ($\text{Cl}_{2(\text{aq})}$) to form chloride ions and copper(II) ions, both in solution.

- Write a balanced equation (including states) for the reaction described.
- State the “oxidation number” for each species in the equation, and hence state which species has been oxidized and which has been reduced.
- Write half-equations for the reaction, and calculate the cell voltage which would be produced if this reaction was used in a Galvanic cell under standard conditions.

31. (6 marks)

The ordinary dry cell (Leclanche cell) and the silver oxide “button cell” both use exactly the same anode reaction, but different cathode reactions.

- Write a half-equation for the anode reaction of both cells.
- Choose either of the cells mentioned above and write
 - the cathode half-equation.
 - the overall cell equation.
- Discuss the impact of each of these cells on society, and their relative cost and practicality.

32. (10 marks)

- What are “isotopes”?
- What, in general terms, determines whether an isotope is stable or radioactive?
- List the 3 types of radioactive emissions, and for each state what it is.
- Describe a method for making “Transuranic” elements.

33. (3 marks)

Identify 3 different instruments or processes that can be used to detect nuclear radiations.

34. (5 marks)

- Identify one use of a named radioisotope in industry.
- Identify one use of a named radioisotope in medicine, and explain how its use is related to its chemical properties.

Answer Section

Worksheet 1

- | | |
|---------------------------|---------------------------|
| a) fuels | b) petrochemicals |
| c) ethylene | d) double |
| e) reactive | f) Addition |
| g) bromine | h) de-colourized |
| i) Cracking | j) heat or catalysts |
| k) octane | l) gas |
| m) polymers/polythene | n) addition |
| o) polyethylene | p) pressure & temperature |
| q) low | r) side-branches |
| s) flexible | t) cling-wrap |
| u) catalyst | v) pack together |
| w) high | x) plastic carry bags |
| y) polyvinyl chloride | z) vinyl chloride |
| aa) chloroethene | ab) dispersion |
| ac) harder | ad) rigid |
| ae) drain pipes & gutters | af) styrene |
| ag) ethenylbenzene | ah) benzene |
| ai) dispersion | aj) hard and rigid |
| ak) condensation | al) water molecule |
| am) polyester & PET | an) proteins & starch/DNA |
| ao) cellulose | ap) glucose |
| aq) wall | ar) cotton & linen |
| as) rayon | at) glucose |
| au) ethanol | av) ethylene |
| aw) glucose | ax) PHB |
| ay) Bacillus magaterium | az) Genetic Engineering |
| ba) corn | |

Worksheet 2

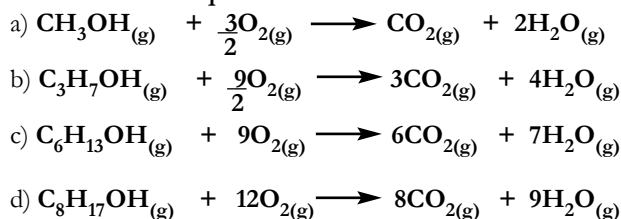
Part A

- | | |
|---|----------------------------|
| a) homologous | b) $C_nH_{2n+1}OH$ |
| c) alcohols | d) -OH |
| e) polar | f) dipole |
| g) hydrogen | h) higher |
| i) soluble | j) solvents |
| k) polar & non-polar | l) fuels |
| m) energy content | n) addition |
| o) water | p) sulfuric acid |
| q) ethanol to ethylene | r) concentrated |
| s) dehydration | t) glucose |
| u) fermentation | v) enzymes |
| w) yeast | x) sugar/carbohydrate |
| y) yeast | z) 25 |
| aa) anaerobic | ab) 15% |
| ac) fractional distillation | ad) 95% |
| ae) sugar | af) distillation |
| ag) vinegar | ah) carbon dioxide & water |
| ai) heat given out when 1 mole of fuel is burned completely | |
| aj) standard states at SLC | ak) exo- |
| al) negative | am) positive |
| an) increases | ao) alkane |
| ap) renewable | aq) technology |
| ar) Greenhouse | as) 20% |
| at) cultivated for "ethanol farming" | |
| au) distillation | av) engines |

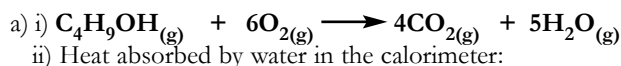
Worksheet 2 (cont)

Part B Practice Problems

1. Combustion Equations



2. Heat of Combustion



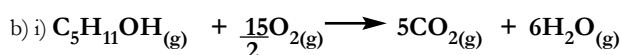
$$\begin{aligned}\Delta H &= -mC\Delta T \\ &= -200 \times 4.18 \times 23 \\ &= -19,228 \text{ J} \\ &\equiv \mathbf{19 \text{ kJ of heat released.}}\end{aligned}$$

This is the heat released for 1.4g of butanol burnt.

$$\therefore \text{Heat of Combustion per gram} = 19/1.4 = \mathbf{13.57 \text{ kJ/g}} \\ \equiv \mathbf{14 \text{ kJ/g}}$$

$$MM(\text{butanol}) = 74.1 \text{ g}$$

$$\therefore \text{Molar Heat of Combustion} = 13.57 \times 74.1 \equiv \mathbf{1000 \text{ kJmol}^{-1}}$$



ii) Heat absorbed by water in the calorimeter:

$$\begin{aligned}\Delta H &= -mC\Delta T \\ &= -150 \times 4.18 \times 12 \\ &= -7,524 \text{ J} \\ &\equiv \mathbf{7.5 \text{ kJ of heat released.}}\end{aligned}$$

This is the heat released for 0.50g of pentanol burnt.

$$\therefore \text{Heat of Combustion per gram} = 7.5/0.50 = \mathbf{15 \text{ kJ/g}}$$

$$MM(\text{pentanol}) = 88.2 \text{ g}$$

$$\therefore \text{Molar Heat of Combustion} = 15 \times 88.2 \equiv \mathbf{1300 \text{ kJmol}^{-1}}$$

$$c) \Delta H_c(\text{ethanol}) = 1367 \text{ kJmol}^{-1} \quad MM(\text{ethanol}) = 46.1 \text{ g}$$

$$\therefore \Delta H_c \text{ per gram} = 1367 / 46.1 = 29.7 \text{ kJ/g}$$

$$\text{Heat released by burning } 2.80 \text{ g} = 29.7 \times 2.80 = 83.0 \text{ kJ}$$

$$\text{i.e. } \Delta H = -83,000 \text{ J}$$

$$\begin{aligned}\Delta H &= -mC\Delta T, \text{ so } \Delta T = \Delta H / -mC \\ &= -83,000 / -500 \times 4.18 \\ &= \mathbf{39.7^\circ C}\end{aligned}$$

$$d) \Delta H_c(\text{pentanol}) = 3330 \text{ kJmol}^{-1} \quad MM(\text{pentanol}) = 88.2 \text{ g}$$

$$\therefore \Delta H_c \text{ per gram} = 3330 / 88.2 = 37.8 \text{ kJ/g}$$

$$\text{Heat released by burning } 0.50 \text{ g} = 37.8 \times 0.50 = 18.9 \text{ kJ}$$

$$\text{i.e. } \Delta H = -18,900 \text{ J}$$

$$\begin{aligned}\Delta H &= -mC\Delta T, \text{ so } \Delta T = \Delta H / -mC \\ &= -18900 / -150 \times 4.18 \\ &= \mathbf{30.1^\circ C}\end{aligned}$$

In Q(b) the same amount of fuel produced a temp rise of only 12°C. This shows the inefficiency of the simple "can of water" calorimeter, which captured less than half the heat released.

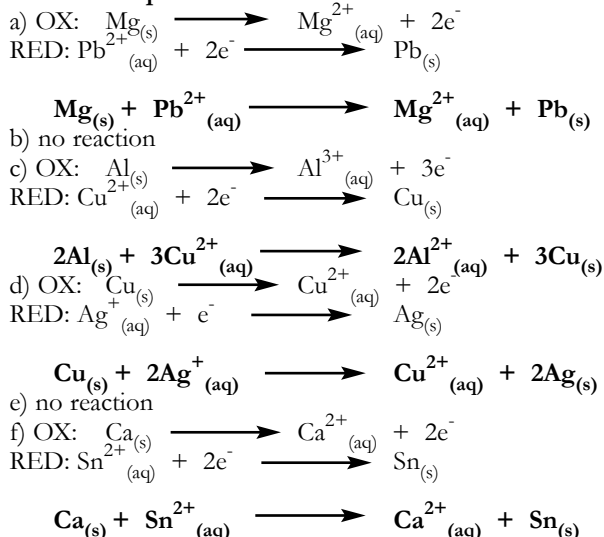
Worksheet 3

Part A

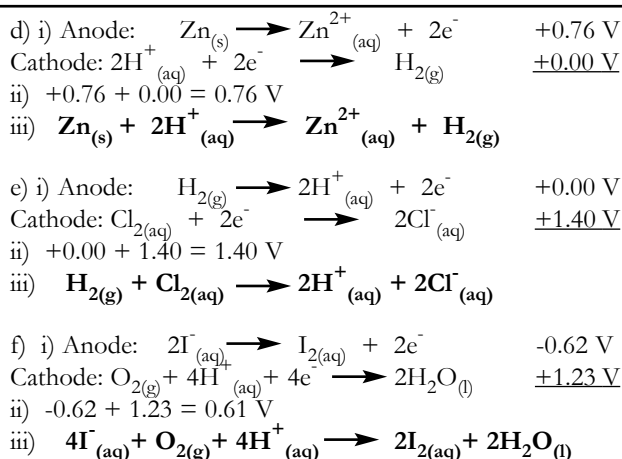
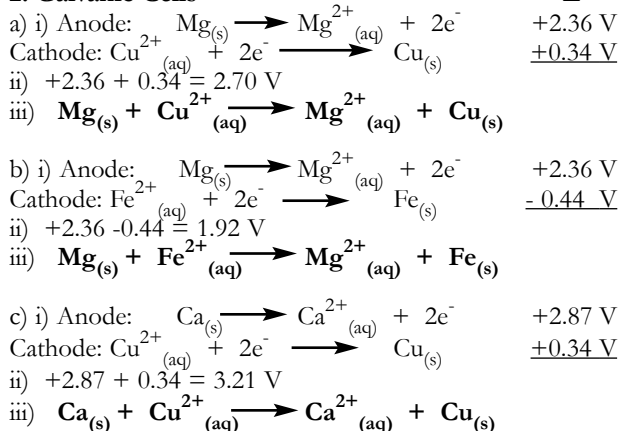
- | | |
|--|----------------------|
| a) Activity | b) ions |
| c) higher up | d) displace |
| e) lose | f) oxidation |
| g) gain | h) reduction |
| i) oxidation-reduction | j) Redox |
| k) electrons | l) oxidation |
| m) reduction | n) cells & batteries |
| o) half-cells | p) anode |
| q) cathode | r) electrons |
| s) anode | t) cathode |
| u) Salt | v) ions |
| w) electric charge | x) EMF |
| y) Standard Electrode | z) standard |
| aa) hydrogen ions \longrightarrow hydrogen gas | |
| ab) zero | ac) higher up |
| ad) oxidation | ae) reversed in sign |
| af) add | ag) voltage/ EMF |
| ah) positive | ai) spontaneously |
| aj) exo- | ak) dry |
| al) silver oxide button cells | |

Part B Practice Problems

1. Metal Displacement Reactions



2. Galvanic Cells



Worksheet 4

- | | |
|-------------------------|---------------------------|
| a) element | b) number |
| c) mass numbers | d) neutrons |
| e) isotopes | f) average |
| g) chemical | h) radioactive |
| i) Alpha | j) 2 protons & 2 neutrons |
| k) β | l) electrons |
| m) Gamma | n) high |
| o) protons to neutrons | p) 80 |
| q) uranium | r) 92 |
| s) Transuranic | t) neutron |
| u) particle accelerator | v) bombardment |
| w) nuclear reactor | x) 60 |
| y) beta and gamma | z) sterilizing |
| aa) welded joints | ab) cancer/tumours |
| ac) gamma | ad) photographic |
| ae) Geiger | af) ionization |
| ag) Scintillation | ah) flash of light |
| ai) safety | |

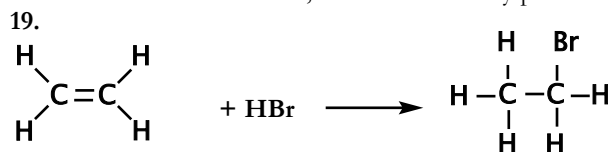
Practice Questions

Part A Multiple Choice

- | | | | | |
|------|------|-------|-------|-------|
| 1. B | 5. D | 9. C | 13. A | 17. D |
| 2. C | 6. B | 10. D | 14. C | 18. C |
| 3. A | 7. A | 11. B | 15. A | |
| 4. D | 8. C | 12. A | 16. A | |

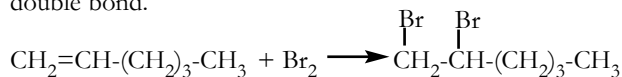
Part B Longer Response

In some cases there may be more than one correct answer possible. The following "model" answers are correct, but not necessarily perfect.



20.

Hexene will undergo an addition reaction across the C=C double bond.

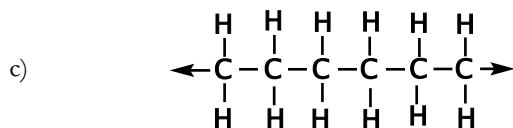


The Br_2 is consumed and its colour disappears.

Hexane has no double C=C bond, so does not react.

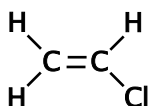
21.

- a) "Cat-Cracking" refers to Catalytic Cracking; the use of a catalyst (zeolite minerals) to break long chain hydrocarbons into smaller molecules.
b) The double C=C bond in ethylene molecules allows thousands of them to undergo addition reactions with each other. They join in very long chains of polyethylene.



22.

- a) Common name = vinyl chloride
Systematic = chloroethene
b) Compared to polyethylene, PVC has one chlorine atom in place of a hydrogen on each monomer unit. This greatly increases the molecular weight, and therefore the dispersion forces between PVC molecules. The PVC molecules "stick" together much more strongly, making the plastic harder and more rigid.



While its properties make polyethylene suitable for cling-wrap film, the tougher PVC is used for drainage pipes and guttering.

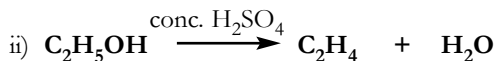
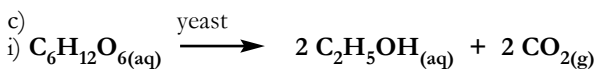
23.

- a)
- 2 glycine molecules joined
- $$\begin{array}{c} \text{H} & & \text{H} & & \text{O} & & \text{H} \\ | & & | & & || & & | \\ \text{H}-\text{N}-\text{C}-\text{C} & - & \text{N}-\text{C}-\text{C} \\ | & & | & & | & & | \\ \text{H} & & \text{H} & & \text{H} & & \text{O} \\ & & & & & & \text{H} \end{array}$$
- water

- b) as each pair of glycines join together, a molecule of water is formed. The appearance of water is termed "condensation".

24.

- a) It is a long-chain, condensation polymer. The monomer is glucose.
b) It is "renewable" because it can be produced by growing plants.



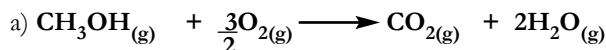
25.

- a) Alkanes: low m.p. & b.p. and are not soluble in water. Alkanols: much higher m.p. & b.p.. Smaller alkanols are fully soluble (miscible) in water. Solubility decreases with size.
b) Alkanes have entirely non-polar covalent bonds. Therefore, the only inter-molecular forces are weak dispersion forces, so m.p. & b.p. are very low. Since non-polar, there is nothing to attract to, or bond with the polar water molecule; hence insoluble. Alkanols have the polar -OH group. This creates a dipole, and hydrogen bonding between molecules. (higher m.p. & b.p.) Alkanols also form hydrogen bonds with water molecules, so they are soluble.

26.

- a) water, sugar and yeast
b) container sealed to be anaerobic. Temperature kept constant around 25°C.
c) Mixture bubbled. Gas produced turned limewater milky; CO₂. Odour changed.
d) The flask and contents lost mass, due to the loss of CO₂ gas produced.
e) Fractional distillation.

27.



- b) Heat absorbed by water in the calorimeter:

$$\begin{aligned} \Delta H &= -mC\Delta T \\ &= -100 \times 4.18 \times 14 \\ &= -5,852 \text{ J} \\ &\equiv 5.9 \text{ kJ of heat released.} \end{aligned}$$

- c) i) Heat of Combustion per gram = 5.9/0.58 = 10 kJ/g

- ii) MM(methanol) = 32.0g

Molar Heat of Combustion = 10 x 32.0 = 320 kJmol⁻¹.

- d) A large amount of the heat released will NOT be collected by the calorimeter, so the experimental value is much lower than the "text" value.

28.

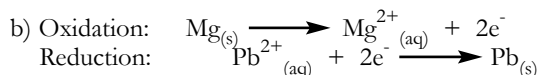
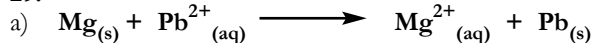
Ethanol has great potential as an alternative fuel because it can be made from plant material (e.g. sugar) and is therefore renewable, sustainable and "Greenhouse-friendly", at least in theory. It can be added to petrol up to about 20% without engine modification, and can be used to "extend" petrol supplies.

However, to use 100% ethanol fuel requires total re-design and replacement of engines. Also, to make enough ethanol to totally replace petrol would require vast amounts of crop-land to be devoted to "ethanol-farming"; this could disrupt food production. Also, the distillation process uses a lot of energy, and current technology uses fossil fuels, so it is not really renewable, nor Greenhouse-friendly.

It seems unlikely that ethanol will realize its great potential until technology develops to allow:

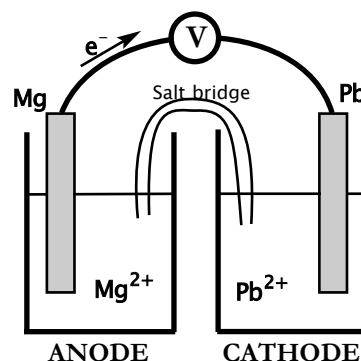
- renewable energy (e.g. solar power) distillation, and
- economic, efficient production of glucose from cellulose plant wastes (so special crops do not have to be grown).

29.

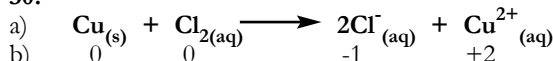


c)

- d) Cell EMF
= +2.36 - 0.13
= 2.23 V

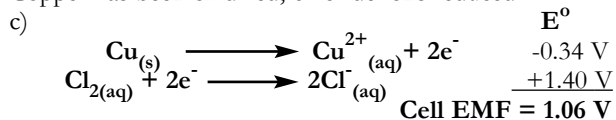


30.

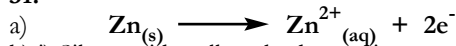


Oxidation numbers below each species.

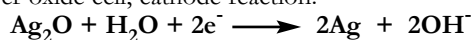
Copper has been oxidized, chloride ions reduced.



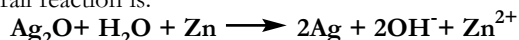
31.



b) i) Silver oxide cell, cathode reaction:



ii) overall reaction is:



c) The first dry cells were invented to power morse-code telegraph stations, but once they were available, many other portable electric devices were invented; flashlights, portable radios, etc. Therefore, the dry cell changed society by making possible a whole host of new technologies.

The tiny silver oxide “button cell” has allowed further miniaturization of portable electrical technology. (e.g. hearing-aids, remote-locking key-ring devices)

“Ordinary” dry cells can be made very cheaply, so they are very practical for convenient, everyday use. Although button cells are about 10 times more expensive, their small size makes them practical and worth the cost for use in miniature devices like hearing aids.

32.

a) Isotopes are atoms of the same element which have different numbers of neutrons, and therefore different Mass Numbers.

b) Stable isotopes must have a particular ratio between protons:neutrons (the ratio is very close to 1:1 in small atoms). If the ratio is not correct, or if the atom is too large (mass number above about 210), the nucleus is unstable and may “decay” radioactively.

c) Alpha: particle- 2 protons & 2 neutrons

Beta: particle- electron

Gamma: high frequency electromagnetic wave.

d) Fusion in a particle accelerator:

Large atomic nuclei can be accelerated to very high speeds by magnetic fields and allowed to collide. Sometimes 2 nuclei will “fuse together” to form a nucleus of a “transuranic” element.

33.

Photographic film can be “exposed” by radiations, and thereby used to detect emissions.

The “Geiger-Muller” tube detects radiations by electronically registering the ionization it causes in a gas such as argon.

A “Scintillation Counter” detects the flash of light which some chemicals emit when they are struck by radiation.

34.

a) Cobalt-60 emits gamma rays which are beamed through welded metal joints (e.g. in aircraft industry) to check the quality of the join.

b) Iodine-131 is used to treat cancers of the thyroid gland. The gland actively absorbs iodine, so the chemistry of I-131 ensures that the isotope become concentrated within the thyroid, where the radiation destroys tumour cells, with minimum damage to healthy tissue. Its very short half-life ensures that it disappears rapidly.

NOTICE ANY ERRORS?

Our material is carefully proof-read
but we're only human

If you notice any errors, please let us know

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keep it simple science

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