How chemistry serves society

The importance of chemistry

Chemistry is the foundation of many industries. Almost everything we use in our daily lives is made from the products of the chemical industry: cars, electronic devices, paints, perfumes, disinfectants, pharmaceuticals and much of our clothes. Few metals are found free in nature; most occur as *oxides*, *sulfides* or other *compounds* which must be chemically decomposed to extract the metal. So many chemicals are produced from *petroleum* that the term 'petrochemicals' is used to describe them; they include fuels (liquid and gas), oils, *lubricants*, *solvents*, plastics, fibres, dyes, inks and many more.

This lesson reviews many aspects of chemistry and shows how they are applied in industry.

Chemical formulae

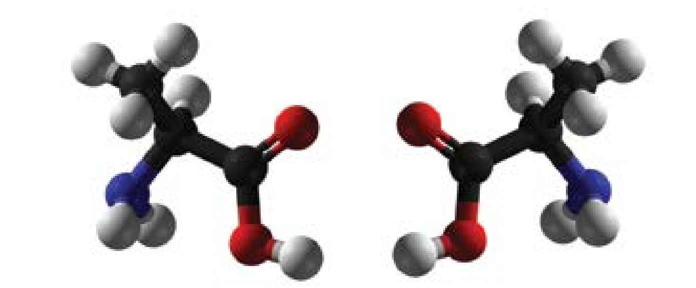
A *chemical formula* is a compact way to describe the chemical composition of a substance. It tells what elements the substance contains and the number of atoms of each of these elements in one molecule of the substance. A chemical formula does not usually describe how the atoms are bonded but a *structural formula* does. Two different substances could have the same chemical formula but would have different structural formulae. For example C_2H_6O could have the following structural formulae:

CH_3-O-CH_3 (methoxymethane) or C_2H_5OH (ethanol).

These two substances have different *functional groups* and are referred to as *functional isomers*. *Structural isomers* on the other hand have the same functional groups but still have different structures; e.g. propan-1-ol and propan-2-ol ($CH_3.CH_2.CH_2OH$ and $CH_3.CHOH.CH_3$)

Sometimes molecules with the same structural formula can differ in another way; one may be the mirror image of the other and their crystalline forms are also mirror images of one another. For example nineteen of the twenty commonly occurring amino acids show this property.

If you make models of alanine ($CH_3.CHNH_2.COOH$) you will find that there are two possible structures. Such pairs are known as *stereoisomers*.



Stereoisomers of alanine (one of the simpler amino acids)

Hydrocarbons

Hydrocarbons are compounds of hydrogen and carbon only. There are millions of such compounds and this is due to the remarkable ability of carbon atoms to form stable chains. By contrast there are only two compounds of hydrogen and oxygen – water and hydrogen peroxide (H_2O and H_2O_2).

The simpler hydrocarbons have no *isomers* but the heavier ones have many isomers. There is only one structure for CH_4, C_2H_6 and C_3H_8 (methane, ethane and propane) but there are eighteen ways to construct a model of an octane molecule (C_8H_{18}), twelve of which have a corresponding stereoisomer.

Hydrocarbons are widely used as fuels and when they burn in air or oxygen they produce carbon dioxide and water.

Stoichiometry

Stoichiometry is concerned with the *ratios* in which substances combine or react with one another. The ratios can be expressed in terms of the relative masses or relative numbers of atoms. For example, water molecules (H_2O) contain one oxygen atom and two hydrogen atoms, so the numerical ratio of hydrogen to oxygen is 2:1. However oxygen atoms are sixteen times more massive than hydrogen atoms and so the mass ratio of hydrogen to oxygen in water is 2:16 or 1:8. Alternatively we could say that water is 11.1% hydrogen and 88.9% oxygen [i.e. 2/(2+16) and 16/(2+16)].

A worked example

Question: If a car does 18 kilometres per litre of *petrol* how much carbon dioxide does it emit per kilometre?

Answer: Let us assume for simplicity that petrol is just octane or iso-octane (C_8H_{18}). When it burns, carbon dioxide and water are produced. One molecule of octane contains 8 carbon atoms; to convert all these to CO_2 requires 16 oxygen atoms or 8 oxygen molecules. Similarly the 18 hydrogen atoms are converted to water and this requires 9 oxygen atoms or 4.5 oxygen molecules. So the balanced *chemical equation* is:

$C_8H_{18} + 12.5\ O_2 \longrightarrow 8CO_2 + 9\ H_2O + 5075$ MJ per *mole* of octane.

Using the *relative atomic masses* from the *Periodic Table* we can find the mass of a mole of octane and of 8 moles of CO_2:

The mass of 1 mole of octane is (8×12) g + (18×1) g = 114 g

The mass of 8 moles of carbon dioxide is (8×12) g + (16×16) grams = 352 g. So burning 114 g of octane produces 352 g of carbon dioxide. Since the density of octane is 0.7 g/cm³, the volume of 114 g of octane is 114/(0.7) = 163 cm³.

Burning 163 cm³ of octane produces 352 g of CO_2

Burning 1 cm³ of octane produces 352/163 g of CO_2

Burning 1000 cm³ of octane produces 1000×352 /163 g of CO_2, i.e. 2160 g of CO_2.

So for every litre of petrol burned 2160 g of CO_2 are produced.

How chemistry serves society

The car in question travels 18 kilometres per litre of petrol. So the car emits (2160/18) grams of CO_2 for every kilometre it travels, i.e. it emits 120 g of CO_2 per kilometre. This rating is used nowadays to describe the *fuel efficiency* of motor cars.

Exothermic and endothermic reactions

When fuel is burned energy is released; such reactions are said to be exothermic, i.e. they give out heat. To reverse an exothermic reaction (even if it were possible) would require an input of at least as much energy again. Regardless of the chemical pathways used to produce a particular substance, its final internal energy will be the same. This principle was first proposed in 1840 by Germain Hess and is now known as Hess's Law.

For this reason synthesising fuels from their elements always requires more energy input than can be recovered from their combustion.

Heat loss

In order to retrieve the energy 'stored' in fuel it is usually burned. This can be done in a furnace with up to 97% efficiency and very little heat is wasted.

Using chemical energy to produce motion is not nearly so efficient. A motor car engine is typically less than 20% efficient because of incomplete combustion, heat loss in the *exhaust*, *internal friction* in the engine and air *drag*. About 80% of the energy in the fuel is lost as heat to the environment.

Even in stationary engines (like those used in factories or power stations) 50% of the energy may be lost as heat. However, by combining power and heating requirements, overall efficiencies of around 80% can be achieved. Developments such as these will become increasingly important as *fossil fuel* resources become more difficult to find and exploit.

Royal Dutch Shell

Shell is a global group of energy and petrochemicals companies. With around 90,000 employees in more than 80 countries and territories, Shell helps to meet the world's growing demand for energy in economically, environmentally and socially responsible ways.

Shell has been exploring for, and producing, oil and gas for more than a century, using the most innovative technologies available.

The company is meeting the challenge of growing energy demand by discovering new hydrocarbon resources that can be produced economically, efficiently and safely.

While Shell believes that oil and gas will be integral to the global energy needs for economic development for many decades to come, the company is also involved in the development of renewable energy sources as an alternative to fossil fuels. These include solar energy and second generation biofuels.

In Ireland, Shell is the lead operator in the Corrib Gas Project. The Corrib field is located 83 km off the coast of County Mayo has the potential to supply up to 60% of the country's gas needs at peak production.

For further information on the Corrib gas project visit **www.corribgas.ie**

Find this and other lessons on **www.sta.ie**

Syllabus References

The relevant syllabus references are:

Leaving Certificate Chemistry (p. 49-52)

The Mole (p.12)

Chemical Formulas: Empirical and molecular formulas. Percentage composition by mass. Structural formulas.

Chemical Equations (p. 13): Chemical equations. Balancing chemical equations. Calculations based on balanced equations using the mole concept (balanced equations will be given for all calculations).

Structure of Aliphatic Hydrocarbons (p. 15): Alkanes, alkenes and alkynes as homologous series.

Exothermic and Endothermic Reactions (p. 16)

Science and Technology in Action is widely used for project work in **Transition Year**.

Learning Outcomes

On completion of this lesson, students should be able to:

- Outline some of the ways in which chemistry is fundamental to industry
- Explain what is meant by the term isomer and make models of functional, structural and stereo isomers
- Balance simple chemical equations and calculate relative reacting masses
- Outline the inefficiencies in heat engines, such as internal combustion engines
- Outline why combined heat and power systems are desirable
- Calculate the carbon dioxide output of a car engine given its efficiency in km/L.

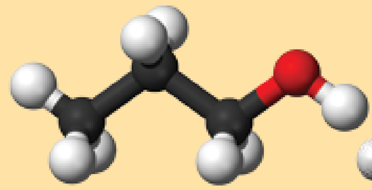
General Learning Points

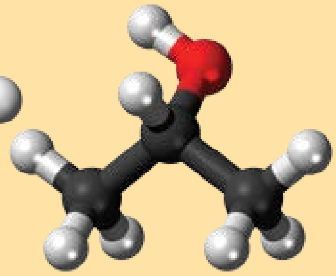
The following points can be used to enhance the lesson content and to inform discussion.

1. Chemistry is concerned with processes in which new substances are produced, i.e. the output substances are different from the input substances.
2. Most of the everyday items we use are made from the products of the chemical industry. In this way manufacturing industry depends on the chemical industry.
3. Different substances can have the same chemical composition, i.e. they can have the same chemical formula but will have different structures (e.g. various structures for octane, C_8H_{18})
4. Furnaces may be nearly 100% efficient but heat engines are rarely better than 50% efficient.

Student Activities

1. Make up models of propan-1-ol and propan-2-ol ($CH_3.CH_2.CH_2OH$ and $CH_3.CHOH.CH_3$). (Black-C, Red - O, White = H)





2. Make up models C_4H_{10}, and C_5H_{12}. How many different arrangements can you make for each of these? (This can be done as a class activity.)
3. (More challenging) How many molecular models can you make with five 'carbons' and twelve 'hydrogens'? (Remember that single bonds can twist but double bonds cannot.)
4. Investigate the efficiency of various types of engines (petrol and diesel internal combustion engines; steam engines and gas turbines).

True/False Questions

a)	A molecular formula indicates what elements the molecule contains and in what proportion.	T	F
b)	A structural formula indicates which atoms are bonded within a molecule.	T	F
c)	Carbohydrates are composed of hydrogen and oxygen only.	T	F
d)	Propane (C_3H_8) has two structural isomers.	T	F
e)	Water is 12.5% hydrogen and 87.5% oxygen.	T	F
f)	Stoichiometry is the study of relative amounts of elements that react or that combine to form to a new substance.	T	F
g)	An endothermic reaction is one that gives out energy.	T	F
h)	The majority of manufactured goods are made from the products of the chemical industry.	T	F
i)	Hydrocarbons in which all the bonds are single bonds are called alkenes.	T	F

Check your answers to these questions on www.sta.ie.

Examination Questions

Leaving Certificate Chemistry (HL), 2005, Q. 6

(a) The octane number of a fuel is described as a measure of the tendency of the fuel to cause knocking, or as a measure of the tendency of the fuel to resist auto-ignition. This number is found by comparing the combustion of the fuel with the combustion of a mixture of two reference hydrocarbons using the same standard engine.

(i) Name both of the reference hydrocarbons present in the mixture used when measuring octane number by this comparison method.

(ii) State two structural features of a hydrocarbon molecule which contribute to it having a high octane number.

(iii) Lead compounds were used in the past to increase the octane number of fuels. Why are lead compounds unsuitable as additives for petrol used in modern cars?

(iv) Identify one additive or type of additive, other than a compound of lead, used to increase the octane number of fuels.

(b) There are three structural isomers of the hydrocarbon of formula C_5H_{12}. In the case of each of these isomers, draw the structure of the molecule and give its systematic IUPAC name.

(c) The combustion of liquid benzene is described by the following equation: $2C_6H_6(l) + 15O_2(g) \longrightarrow 12CO_2(g) + 6H_2O(l)$

Given that the heats of formation of carbon dioxide gas, liquid water and liquid benzene are –394, –286 and 49 kJ mol^{-1} respectively, calculate the heat of combustion of liquid benzene.

Leaving Certificate Chemistry (HL), 2010, Q. 6

The alkanes are a group of hydrocarbons that are commonly used as fuels. The simplest of the alkanes is methane. Another alkane of molecular formula C_8H_{18} has several structural isomers. One of these isomers, 2,2,4-trimethylpentane, has an application in connection with the octane number of a fuel.

(a) What are (i) hydrocarbons, (ii) isomers?

(b) State two important sources of hydrocarbon fuels.

(c) Mention two situations in which there may be a hazardous build-up of methane gas. Why are the levels of methane in the lower atmosphere a cause of environmental concern?

(d) What do you understand by the octane number of a fuel?

What is the significance of the compound 2,2,4-trimethylpentane in relation to octane numbers?

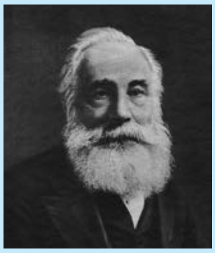
Draw the structural formula of 2,2,4-trimethylpentane.

Did You Know?

- Over the last two hundred years tens of thousands of substances have been isolated from natural sources or synthesised from other chemicals. The term ‘organic’ was originally applied to describe substances derived from plant or animal tissues; the nature of these substances was thought to be completely different from that of ‘ordinary’ chemicals. However in 1828 Friedrich Wöhler synthesised urea ($NH_2.CO.NH_2$) from laboratory chemicals. This significant development showed that living material was also composed of ‘chemicals’.
- Since carbon compounds predominate in living things, the term ‘organic chemistry’ refers to the chemistry of carbon compounds in general. However the chemistry of carbonates, carbon monoxide and carbon dioxide is often included in inorganic chemistry.

Biographical Notes

William Henry Perkin (1838 –1907)



William Perkin, whose father was a carpenter, was born in London in 1838. While at school his teacher encouraged his interest in chemistry. So at the age of 15 he entered the Royal College of Chemistry in London where he was taught by Hofmann, famous, not least, for his invention of the Hofmann voltameter.

Three years later, as Hofmann’s assistant, he began looking for a way to make quinine — an extract from the cinchona tree which was used to treat malaria. He continued his research secretly at home and although he did not succeed in making quinine he did produce a stable purple dye. He realised that this could be valuable and so with his brother and a friend he scaled up the production of the dye which he called mauveine. This was the first synthetic dye. In August that same year (1856) while still only eighteen, he patented his dye.

He eventually built a factory to manufacture the dye in large quantities and became very wealthy. He continued his research and discovered ways to synthesise other dyes.

Perkin received many awards and honours and was knighted in 1906. He died the following year of pneumonia and appendicitis.

Revise The Terms

Can you recall the meaning of the following terms? Revising terminology is a powerful aid to recall and retention.

chemical equation, chemical formula, chemistry, compound, density, drag, elements, exhaust, exothermic, fossil fuel, friction, fuel efficiency, functional group, functional isomers, hydrocarbons, idling, isomers, lubricant, mole, oxide, Periodic Table, petrol, petroleum, ratios, relative atomic mass, stereoisomers, stoichiometry, structural formula, structural isomers, sulfide.

Check the Glossary of terms for this lesson on www.sta.ie