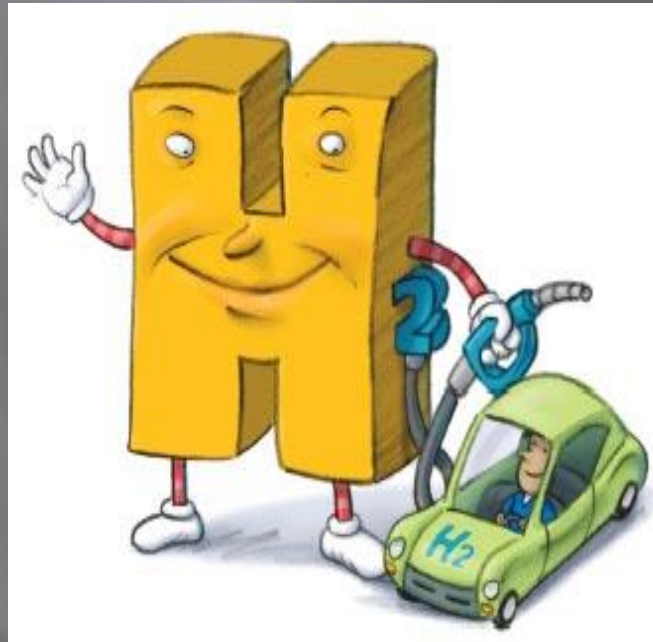


# Unit 2 Hydrogen Fundamentals



# Aims

The aim of this unit is to:

- Identify and understand the fundamentals of atomic structure.
- Understand the working fundamentals, characteristics and properties of hydrogen.
- Be able to follow the working properties of hydrogen in comparison to alternative fuels.

# What is an Atom?

Atoms are the basic building blocks of ordinary matter. They join together to form molecules, which in turn form most of the objects around you.

Atoms are composed of particles called protons, electrons and neutrons.

Protons carry a positive electrical charge, electrons carry a negative electrical charge and neutrons carry no electrical charge at all.

The protons and neutrons cluster together in the central part of the atom, called the nucleus, and the electrons 'orbit' the nucleus.

A particular atom will have the same number of protons and electrons and most atoms have at least as many neutrons as protons.

# What is an Element?

An element is a substance that is made entirely from one type of atom.

For example, the element hydrogen is made from atoms containing a single proton and a single electron. If you change the number of protons an atom has, you change the type of element it is.

If you had very, good eyes and could look at the atoms in a sample of hydrogen, you would notice that most of the hydrogen atoms would have no neutrons, some of them would have one neutron and a few of them would have two neutrons.

These different versions of hydrogen are called isotopes. All isotopes of a particular element have the same number of protons, but have a different number of neutrons. If you change the number of neutrons an atom has, you make an isotope of that element.

# What is the difference between Atoms and Elements?

**ELEMENT** - a basic substance that can't be simplified (hydrogen, oxygen and gold, etc...)

**ATOM** - the smallest amount of an element.

**MOLECULE** - two or more atoms that are chemically joined together ( $\text{H}_2$ ,  $\text{O}_2$ ,  $\text{H}_2\text{O}$ , etc...)

**COMPOUND** - a molecule that contains more than one element ( $\text{H}_2\text{O}$ ,  $\text{C}_6\text{H}_{12}\text{O}_6$ , etc...)

# Air and Water



# Air and Water

Air and water are used as the source in the manufacture of many common chemicals and also as a comparative “yardstick” upon which many units of measurements are based.

Air and water are two of the most abundant and familiar chemical compounds on earth. All living organisms must have one or both to survive but both are taken very much for granted.

# Air

The common name given to the atmospheric gases used in breathing and photosynthesis is air. Dry air contains usually 9 gases, which are:-

Gas	Volume
<u>Nitrogen</u> (N <sub>2</sub> )	780,840 ppmv (78.084%)
<u>Oxygen</u> (O <sub>2</sub> )	209,460 ppmv (20.946%)
<u>Argon</u> (Ar)	9,340 ppmv (0.9340%)
<u>Carbon dioxide</u> (CO <sub>2</sub> )	394.45 ppmv (0.039445%)
<u>Neon</u> (Ne)	18.18 ppmv (0.001818%)
<u>Helium</u> (He)	5.24 ppmv (0.000524%)
<u>Methane</u> (CH <sub>4</sub> )	1.79 ppmv (0.000179%)
<u>Krypton</u> (Kr)	1.14 ppmv (0.000114%)
<u>Hydrogen</u> (H <sub>2</sub> )	0.55 ppmv (0.000055%)

# Air

Air is mainly composed of nitrogen, oxygen, and argon, which together constitute the major gases of the atmosphere, 99.964% in fact.

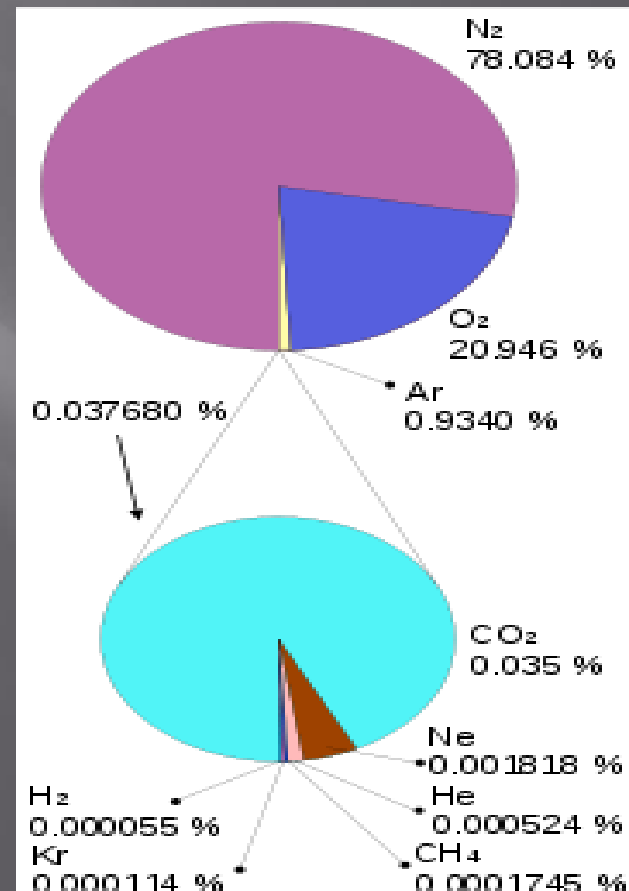
Water vapour accounts for roughly 0.25% of the atmosphere by mass.

The concentration of water vapour (a greenhouse gas) varies significantly from around 10 ppm in the coldest portions of the atmosphere to as much as 5% in very hot, humid air masses.

# Air

The remaining gases are often referred to as trace gases, among which are the greenhouse gases such as:-

- carbon dioxide
- methane,
- nitrous oxide
- ozone



# Air

The fractional distillation of air is often used for the production of its constituent chemicals, particularly nitrogen, oxygen and argon.

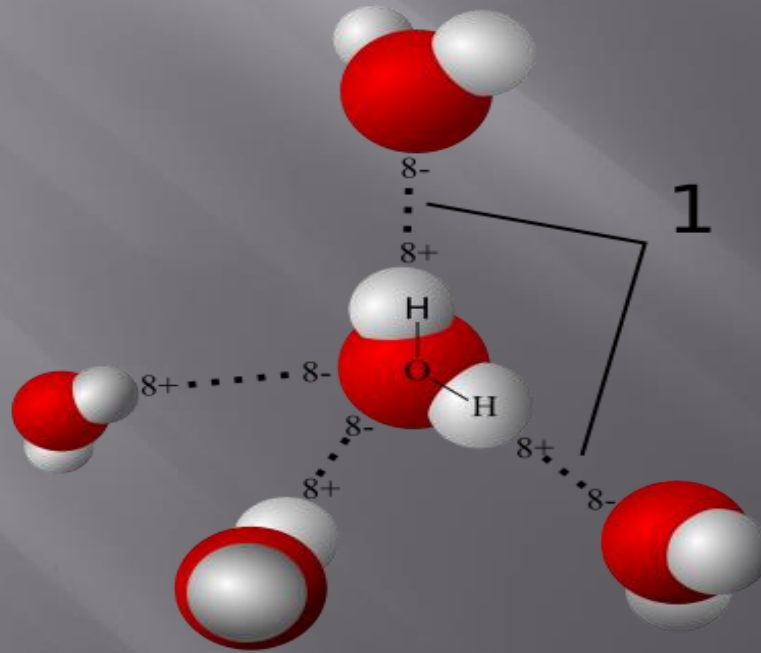
This is achieved by cooling air to less than  $-222^{\circ}\text{C}$  (the condensing point of oxygen) and slowly increasing the temperature to  $-195^{\circ}\text{C}$  (the condensing point of air) to allow the argon and nitrogen to boil off into a condenser.

Liquid nitrogen boils at  $-196^{\circ}\text{C}$  and argon at  $-206^{\circ}\text{C}$ . What remains is 99.83% industrial oxygen.

# Water

Water is a chemical compound with the chemical formula  $\text{H}_2\text{O}$ .

A water molecule contains 1 oxygen and 2 hydrogen atoms connected by covalent bonds.



# Water

Water appears in nature in all three common states of matter (solid, liquid, and gas).

As a liquid at standard ambient temperature and pressure, it often co-exists on Earth with its solid state, ice, and gaseous state.

The intrinsic colour of water and ice is a very slight blue hue, although both appear colourless in small quantities; it is tasteless and odourless and as a vapour it essentially invisible as a gas.

At SATP (Standard Ambient Temperature and Pressure ( $25^{\circ}\text{C}$  and  $100\text{kPa}$ ) water is a liquid.

# Water

When cooled to  $0^{\circ}\text{C}$ , it solidifies to form ice and when heated to  $100^{\circ}\text{C}$  boils to form steam.

1 litre of water has a mass of 1kg which also has a volume of  $1\text{m}^3$ .

The latent heat properties of water make it ideal for use in heat exchangers. It requires 2260 kilo joules of energy to turn 1kg of water into steam.

Water is also used for the production of Hydrogen and Oxygen via electrolysis, when an electric current is passed through it, making it decompose into its constituent components. Hydrogen appears at the cathode (-) and oxygen at the anode (+).

# Oxygen

Oxygen (chemical symbol O) is the most abundant chemical element in the Earth's crust.

It is a colourless, tasteless and odourless gas and makes up approximately 21% of the air we breathe. It is essential for life, is non flammable but is an oxidant. It is slightly heavier than air.

Under ordinary conditions on Earth, Oxygen can exist freely as the diatomic gas  $O_2$  but due to its reactivity it is most commonly within compounds such as Carbon Dioxide and of course, water.

# Properties - Oxygen

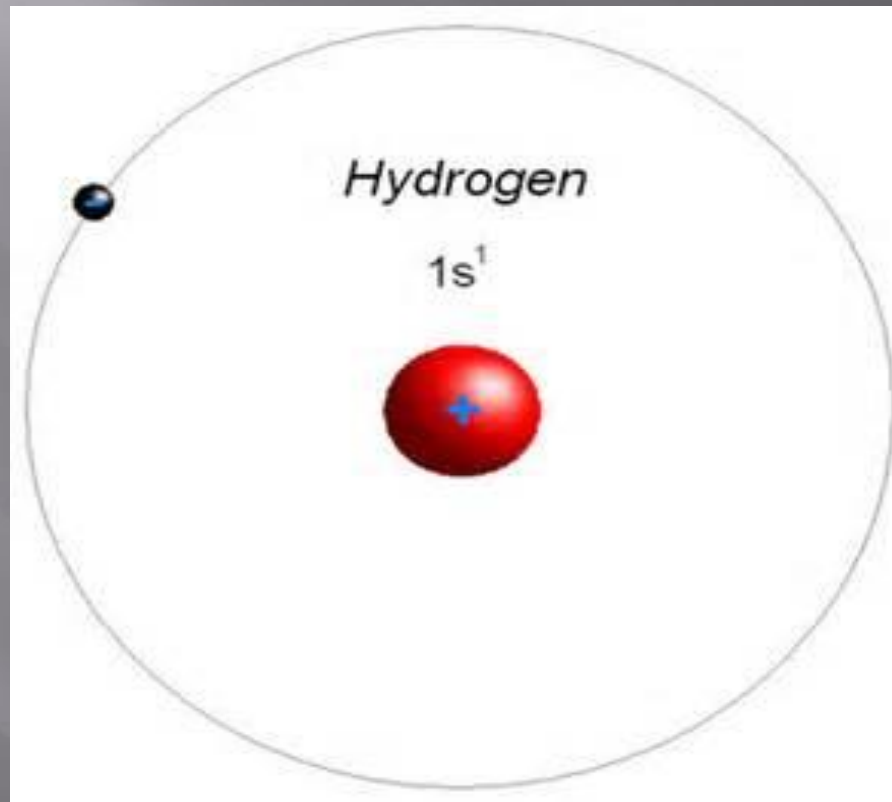
Oxygen is categorised as an oxidant and whilst not flammable it will readily support and accelerate combustion.

High pressure oxygen reacts violently with oils, greases, tarry substances and some solvents. This also includes things like soap, butter and oil-based “barrier” or hand creams.

It is usually stored as a compressed gas at a pressure of around 300 bar.

Q&A

# Why Hydrogen?



# Properties - Hydrogen

The first element on the periodic table.

Hydrogen is a flammable gas that is lighter than air and exists in its natural state as  $H_2$ .

Hydrogen is colourless, odourless, tasteless, non-toxic, and non-poisonous. It's also non-corrosive, but it can embrittle some metals.

Hydrogen is the lightest and smallest element, and it is a gas under atmospheric conditions.

# Properties - Hydrogen

Hydrogen can be stored as a pressurised gas, cryogenically as a cooled liquefied gas or in a chemical compound as a hydride.

Hydrogen is able to seep through many porous materials which would be satisfactory for use with other gases.

As it is so light, it will collect in roof spaces.

Certain steels are subject to attack or embrittlement in hydrogen.

# Composition of other Fuels

All hydrocarbon fuels are molecular combinations of carbon and hydrogen atoms.

There are thousands of types of hydrocarbon compounds, each with a specific combination of carbon and hydrogen atoms in a unique geometry.

The simplest of all hydrocarbons is methane, which is the principal constituent of natural gas. Methane has the chemical formula  $\text{CH}_4$ , which means that each molecule has four hydrogen atoms and one carbon atom.

Other common hydrocarbons are ethane ( $\text{C}_2\text{H}_6$ ), propane ( $\text{C}_3\text{H}_8$ ) and butane ( $\text{C}_4\text{H}_{10}$ ).

These are all considered light hydrocarbons since they contain less than five carbon atoms per molecule and therefore have low molecular weight (a carbon atom is almost 12 times as heavy as a hydrogen atom).

# Comparing Properties of Hydrogen, Diesel and Petroleum

TABLE I. COMPARISON OF PROPERTIES OF HYDROGEN WITH OTHER HYDROCARBON FUELS

Properties	Hydrogen $H_2$	Diesel $C_{10}H_{22}$	Gasoline $C_8H_{18}$
Auto ignition temperature (K)	858	553	714
Minimum ignition energy (mJ)	0.02	20	0.24
Flammability limits (volume % in air)	4-75	0.6-5.5	1.2-7.1
Molecular weight (g)	2.016	170	107
Density ( $kg/m^3$ )	0.0899	850	730
Stoichiometric A/F ratio (mass basis)	34.4	15.2	14.7
Flame velocity (cm/s)	270	22-25	30-50
Specific gravity	0.091	0.833	0.739
Adiabatic flame temp. (K)	2318	2200	2470
Quenching gap (cm)	0.064	0.21	0.2
Heat of combustion (MJ/kg)	120	42.46	43.4
Octane number	130	30	87
Cetane number	---	40-60	Below 15
Boiling point (K)	20.27	645	473

# The Working Properties of Hydrogen

Hydrogen gas is similar to natural gas in that it is lighter than air, so it rises and disperses quickly.

Hydrogen is non-toxic and safe to breathe.

Hydrogen is also odourless, colourless, and tasteless; since it cannot be odorized like natural gas, hydrogen detection and ventilation systems are employed.

Like all fuels, hydrogen is flammable and must be handled properly.

The energy in (1 kg) of hydrogen gas is about the same as the energy in 4.5 litres of petroleum.

Hydrogen has a low amount of energy by volume compared with fuels such as petroleum.

# The Working Properties of Hydrogen

In the U.S. and Europe, hydrogen is transported safely through over 1000 miles of pipelines, in the U.S. 315 million litres of liquid hydrogen is transported annually by truck over U.S. highways without incident.

Hydrogen also can be used to fuel internal combustion engines and fuel cells, both of which can power low- or zero-emissions vehicles such as fuel-cell vehicles.

Fuel-cell vehicles, powered by hydrogen, have the potential to revolutionise our transportation system. They are potentially 2 to 3 times more efficient than conventional internal combustion engine vehicles and produce no harmful tailpipe exhaust – their only emission is water.

# That's it! Well done.

Once you have successfully completed the Unit 2 test you are ready to move onto

Unit 3 Hydrogen Manufacture and Safety

If you would like to learn more about Unit 2 Hydrogen Fundamentals, please ask.

In the mean time, thank you for your attention.

# Next step

Well done with the test everyone.

Your next unit of study is Unit 3 Hydrogen Manufacture and Safety.

Thank you for your attention.