# “DESIGN OF OXYGEN AND HYDROGEN GENERATOR”



***A MAJOR Project Report submitted to the***

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##### DEPARTMENT OF MECHANICAL ENGINEERING BONAFIDE CERTIFICATE

Certified that this project report **“** DESIGN OF OXYGEN AND HYDROGEN GENERATOR **”** is a bonafide work of **“KISHORE THARU, BHAVESH SAHU, ADITYA PRATAP SINGH, ADITYA PATHADE, KHUSHAL THAKRE ”**

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**TABLE OF CONTENTS**

1. INTRODUCTION

* [What is Electrolysis?](https://byjus.com/#what-is-electrolysis?)
* [Electrolytic Process](https://byjus.com/#electrolytic-process)
* [Cell Potential or Voltage](https://byjus.com/#cell-potential-or-voltage)
* [Faraday’s Law of Electrolysis](https://byjus.com/#faraday%E2%80%99s-law-of-electrolysis)
* [Product of Electrolysis](https://byjus.com/#product-of-electrolysis)
* [Factors Affecting Electrolysis](https://byjus.com/#factors-affecting-electrolysis)
* [Electrolysis Applications](https://byjus.com/#electrolysis-applications)

1. Oxygen Production Technologies
   1. How Does it Work?
   2. Polymer electrolyte membrane electrolyzer.
   3. Alkaline electrolyzer.
   4. Solid oxide electrolysis
   5. Why Is This Pathway Being Considered?
   6. Research Focuses On Overcoming Challenges
2. Oxygen
   1. Demand of Oxygen
   2. About Medical Oxygen
   3. Oxygen Applications
3. Hydrogen
   1. Importance of Hydrogen
   2. Properties
   3. Application
4. HHO Gas : **Sustainable treatment for COVID-19 and other respiratory diseases**
5. Conclusion

**Abstract**

Recently some researches concerning how to produce HHO gas using electrolysis have been conducted by using several methods and parameters. The problems were the conditioning of hydrogen generator to produce HHO gas that can affect the efficiency of electric current applied on the equipment. The surface of the anode and cathode used in a hydrogen generator have to be considered. Based on Faraday Law, the number of particles produced by the electrode is proportional to the amount of electric current applied to the electrolysis cell. After some calculation, the surface of the stainless steel electrode used in the hydrogen generator was 66 cm2 . This research conditioning is focused on the variation of electrolyte concentrations used and how much electric current applied to hydrogen generator. Variations of electrolyte concentrations and applied electric current were conducted to see the relation between those parameters and HHO gas produces, and finally, the best set up was achieved to get the highest volume of HHO gas by electrolysis. The best set up was electrolyte concentration of sodium hydroxyl was 0.05 M and applied current was 15 A to produce 0.1028 LPM HHO gas with the electric current efficiency of the hydrogen generator 89.13%.

1. Introduction

Energy has become a basic need for human and researchers keep on aiming for an efficient method of energy conversion. Conventionally, wood, coal, and petroleum are used to generate power. However, these materials are diminishing after being exploited for ages. Therefore, scientists have to keep on researching in finding the new energy resource to overcome this problem. This new energy is called renewable energy. In a quest for finding the solution for this energy problem, we have to explore nature more. Natural gas has been considered as the alternative, and so has the coals. However, natural gas and coals are also considered as fossil fuel, or unrenewable energy, therefore these choices are not sufficient to fulfil the energy needs in the future. Many efforts have been made to substitute hydrocarbon energy into the new alternative of renewable energy. Among the alternative energy are solar energy, the energy potential of water, and biomass energy. Hydrogen energy is one of the most researched among those alternatives since hydrogen is the most found element on earth although it comes in a compound.

Hydrogen can be readily applied to substitute hydrocarbon fuel without changing the current machine structure, causing high heat, and the emitted emission is close to zero [1-4]. To convert water into hydrogen fuel, we need an electrolyzer. The electrolyzer is a machine or equipment to separate water to be hydrogen and oxygen and create brown gas. This machine is also called a hydrogen generator. Electrolysis is the process to separate molecule into its original elements by letting the electric flow on it, while water electrolysis is the process of separating water molecule back to its original elements by letting the electric flow on it. This electrolysis creates HHO gas [5]. HHO gas known as brown gas is obtained from the electrolysis process of water. If the electrolyte used is a base solution such as KOH, an alkaline reaction will occur. In an alkaline reaction, the reduction reaction occurs at the cathode where the water molecule binds electrons (e-) so that it breaks into hydrogen gas (H2) and OH- anions.

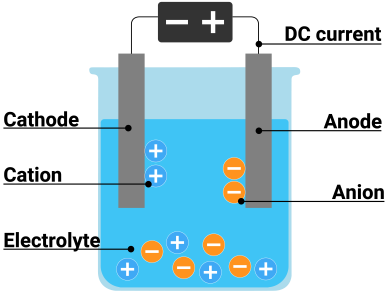
The OH-anion is then attracted to the anode side and split into oxygen gas and H2O molecules. Hydrogen gas has several characteristics, which are colorless, flammable, very light, and very easy to react with other chemicals. However, HHO gas in normal conditions will not burn on its own without fire. The efficiency of electrolysis equipment can be improved by considering the effective surface of electrodes. Therefore when electricity is applied to the electrode, the available current can be minimized.

Electrodes used in this research is a stainless steel 316 and NaOH solution used as the electrolyte. In conditioning electrolysis equipment, the surface of the electrodes has to be considered to by minimizing the over-current that can increase overheat when using the electrolysis equipment. Measurements using flowmeter will be conducted to record the volume of gas output created by generator and composition analyses by using gas chromatography are also conducted. The measurement results are used to calculate HHO gas resulted by the generator and the efficiency of electric current used in the equipment

## **What is Electrolysis?**

Electrolysis is defined as a process of decomposing ionic compounds into their elements by passing a direct electric current through the compound in a fluid form. The cations are reduced at cathode and anions are oxidized at the anode. The main components that are required for conducting electrolysis are an electrolyte, electrodes, and some form of external power source is also needed. Additionally, a partition such as an ion-exchange membrane or a salt bridge is also used but this is optional. These are used mainly to keep the products from diffusing near the opposite electrode.

An acidified or salt-containing water can be decomposed by passing electric current to their original elements hydrogen and oxygen. Molten sodium chloride can be decomposed to sodium and chlorine atoms.



Electrolysis is usually done in a vessel named ‘electrolytic cell’ containing two electrodes (cathode and anode) connected to a direct current source and an electrolyte which is an ionic compound undergoing decomposition, in either molten form or in a dissolves state in a suitable solvent. Generally, electrodes that are made from metal, graphite and semiconductor materials are used. However, the choice of a suitable electrode is done based on chemical reactivity between the electrode and electrolyte as well as the manufacturing cost.

## **Electrolytic Process**

In the process of electrolysis, there is an interchange of ions and atoms due to the addition or removal of electrons from the external circuit. Basically, on passing current, cations move to the cathode, take electrons from the cathode (given by the supply source-battery), and is discharged into the neutral atom. The neutral atom, if solid, is deposited on the cathode and if gas, move upwards. This is a reduction process and the cation is, reduced at the cathode.

At the same time anions, give up their extra electrons to the anode and is oxidized to neutral atoms at the anode. Electrons released by the anions travel across the electrical circuit and reach the cathode completing the circuit. Electrolysis involves a simultaneous oxidation reaction at anode and a reduction reaction at the cathode.

For example, when electric current, is, passed through molten sodium chloride, the sodium ion is attracted by the cathode, from which, it takes an electrode and becomes a sodium atom.

Chloride ion reaches the anode, gives its electron, and become chlorine atom to form chlorine molecule.

Na+(in electrolyte) + e–(from cathode) → Na …. At Cathode

Cl–(from electrolyte) → e– + Cl → Cl2…. At Anode

Electrolysis process, while useful to get elemental forms from compounds directly, it can also be used indirectly in the metallurgy of alkali and alkaline earth metals, purification of metals, deposition of metals, preparation of compounds etc.

[Water Electrolysis](https://byjus.com/jee/water-electrolysis/)

Water electrolysis is a popular method used for different applications in various industries, mainly in the food industry, metallurgy, power plants amongst others. Besides, the components of water which include hydrogen and oxygen have many applications. For instance, hydrogen obtained through electrolysis is a clean, renewable and efficient fuel source.

Water electrolysis is mainly carried out to yield pure hydrogen and oxygen gases. It involves passing an electric current through the water which results in the decomposition of water into hydrogen and oxygen.

* [Factors Affecting the Efficiency of Electrolysis](https://byjus.com/%22#factors-affecting-the-efficiency-of-electrolysis%E2%80%9D)
* [Cell Potential and Thermodynamic Feasibility](https://byjus.com/%22#cell-potential-and-thermodynamic-feasibility%E2%80%9D)
* [Electrolyte for Water Electrolysis](https://byjus.com/#electrolyte-for-water-electrolysis)
* [Water Electrolysis in the Presence of a Base](https://byjus.com/#water-electrolysis-in-the-presence-of-a-base)
* [Water Electrolysis in the Presence of Salts](https://byjus.com/#water-electrolysis-in-the-presence-of-salts)
* [Electrolysis of Water Using Electro Catalysts](https://byjus.com/#electrolysis-of-water-using-electro-catalysts)
* [Electrolyzers](https://byjus.com/#electrolyzers)

However, the[electrolysis](https://byjus.com/jee/electrolysis/) of water is not simple and easy for many reasons.

* Water is very weakly dissociated into hydrogen and hydroxide ions. The concentration of the ions in neutral water is equal (= moles per litre). Electrolysis involves the charge carriers, for the current to flow. So, water with a very small amount of ions is a bad conductor of electricity. So, the electrolysis of pure water will be a very slow process.
* The hydrogen ion is associated with other water molecules and exists as a hydronium ion. So, any hydroxide ion, moving towards the anode, will be neutralized by the hydronium ion, even before it reaches the anode to form oxygen gas. Similarly, any hydrogen present will be neutralized by the hydroxyl ion present near the cathode and will not be, reduced to hydrogen. So, the electrolysis of water to hydrogen and oxygen will be very small. The electrolysis also involves the transfer of electrons from the anion to the anode and cathode to cations.
* In the electrolysis of water, electrodes are inert solids like platinum/palladium whereas electrolyte is a solute in a solution and the product is a gas.

## **Factors Affecting the Efficiency of Electrolysis**

The efficiency of electrolysis or the electron transfer depends on many factors such as;

i) The number of available cations and anions in the solution.

ii) Mobility rate of the ions to reach the electrode.

iii) Activation energy that is needed for the electron transfer from the electrode to the electrolyte ions.

iv) The effect of the gas bubble surrounding the electrode on the further electrotransfer etc.

Crossing over of several interfaces (solute- liquid, solute-solid, solid-gas) results in the increase of energy requirements for the electrolysis (overvoltage) than predicted by the thermos-dynamical Gibbs energy.

**Also Read:** [Gibbs Free Energy](https://byjus.com/jee/gibbs-free-energy/)

## **Principle of Water Electrolysis**

Two electrodes or plates that are made from an inert metal such as platinum or iridium are placed in the water. A DC electrical power source is connected to these plates. At the cathode (where electrons enter the water) part Hydrogen will appear. On the anode side, oxygen will appear. If we consider the ideal faradaic efficiency, hydrogen will be produced twice the amount of oxygen. On the other hand, both will be proportional to the total electrical charge conducted by the solution. However, in some cells side reactions can occur and different products are formed with less than ideal faradaic efficiency.

## **Electrolysis of Water – Cell Potential and Thermodynamic Feasibility**

Half reactions in the electrolysis of pure water at pH=7, and at 25°Care-

At cathode: 2H2O(l) + 2e– → H2(g) + 2OH– E° = -0.42 V

At anode: 2H2O → O2(g) + 4H+ + 4e– E° = +0.82 V

The net reaction of electrolysis of water is given as;

2H2O(l) → 2H2(g) + O2(g) E° = -1.24 V

The cell potential of electrolysis of pure water is negative and hence is thermodynamically unfavourable. Because of the low concentration of ions and the interfaces to be crossed electrons an extra voltage (Overvoltage) at each electrode is needed to about 0.6V.

In practice, continuous electrolysis of pure water is possible only at an external voltage of 2.4V. Since the electrolysis of pure water is thermodynamically non-feasible, methods to make it kinetically feasible are being investigated.

One of the methods is to increase the conductivity by increasing the number of ions available by adding acid, base, or non-reacting salts.

## **Electrolyte for Water Electrolysis**

It is very important to choose the right electrolyte for water electrolysis. Why is it important? If we look at the anion from the electrolyte it usually competes with the hydroxide ions to release an electron. If an electrolyte anion has a less standard electrode potential than hydroxide it will be oxidized instead of the hydroxide. Therefore, oxygen will not be produced. In the case of a cation, if it has a greater standard electrode potential than a hydrogen ion it will be reduced. In this case, hydrogen gas will not be produced.

## **Water Electrolysis in the Presence of Acids (pH lower than 7)**

Additional hydrogen ions from acid will be reduced at the cathode while water will be oxidized at the anode. Half reactions in an acid medium are;

At cathode: 2H+ + e– → H2E° = +0.0 V

At anode: 2H2O → O2(g) + 4H+ + 4e– E° = +1.23 V

Net reaction is written as 2H2O → O2(g) + 2H2 E° = -1.23 V

The electrolysis takes place at a much lower potential than pure water (2.4V).

## **Water Electrolysis in the Presence of a Base (pH higher than 7)**

Additional hydroxyl ions, release their electrons to anode, while electrons at the cathode oxidize water molecules near it. Half reactions of electrolysis in the presence of a base are-

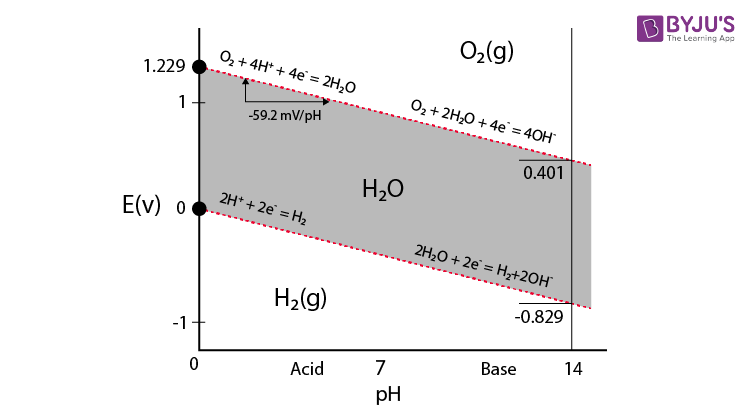
At cathode: 2H2O(l) + 2e–→ H2(g) + 2OH– E° = -0.83 V

At anode: 4OH– → O2 + 2H2O + 4e–E° = +0.4 V

Net reaction is 2H2O → O2(g) + 2H2 E° = -1.23 V

Like electrolysis in an acid medium, electrolysis in the basic medium also needs much lower potential.

Pourbaix diagram gives the equilibrium regions of water, hydrogen and oxygen at various electrode potentials.



## **Water Electrolysis in the Presence of Salts**

Salts are 100%dissociate into cations and anions in water and hence increase the ionic concentration for increasing conductivity. But the cations and anions from the salt also will be attracted towards the electrodes and hence become competitors to the decomposition of water to produce hydrogen and oxygen. So, the selection of salts with non-competing ions becomes necessary.

Salts containing lesser standard electrode potentials than hydrogen and hydroxide ions are suitable for the electrolysis of water.

Ions of first and second group elements (Li, Na, K, Mg, Ca, Ba, etc.) have lower standard potential than hydrogen ions and will not be reduced and allow hydrogen ions from water to hydrogen.

Non-reactive anions like nitrate, sulphate ions have lesser standard reduction potential than hydroxide ions. Sulphate oxidation to peroxy-sulphate has a reduction potential of +2.1V.

Non-soluble, solid polymeric ionic compounds (Nafion), has been found to help electrolysis of water in less than 1.5V.

## **Electrolysis of Water Using Electro Catalysts**

Electro-catalysts are substances that accelerate electrochemical reactions without being consumed in the reaction like a catalyst in chemical reactions. Catalysts take the reaction through a different path of lower activation energy. High surface area, larger activation centres are the ability of the catalyst in increasing the reactivity.

The activity of the inert electrode like platinum can be, enhanced by modification of the surface by

i) Increasing the surface area with nanoparticles or alloying with catalytic d-block elements and changing the electronic state coated with other catalytic substances to enhance the electrolysis.

ii) Coating the electrode surface with catalytically active substances, like enzymes.

## **Electrolyzers**

The electrolytic cell used for the electrolysis of water is the electrolyzer. Depending on the transporter of the electrolyte, electrolyzer can be divided into three types;

### ****Polymer Electrolyte Membrane (PEM) Electrolyzer****

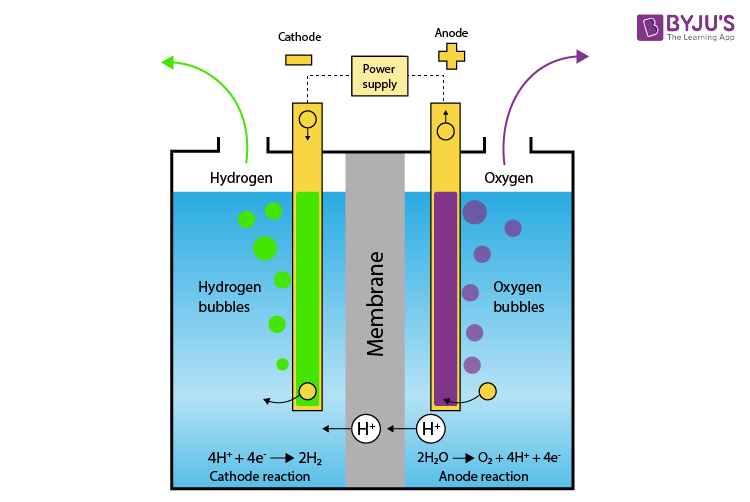
A polymer such as Nafion separates the electrodes and allows hydrogen ions formed by the oxidation of water at the anode to pass through it to the cathode compartment for discharge and form hydrogen gas.

### ****Alkaline Electrolyzers****

Dilute aqueous sodium (or potassium) hydroxide used in the electrolysis provides and movement of hydroxide ions to the anode to form oxygen.

### ****Solid Oxide Electrolyzer****

Ceramic oxide separates the electrodes. At the cathode, water is reduced to hydrogen and oxide ions. The oxide ions pass through the ceramic oxide to the anode to become oxygen gas. This is used at high temperatures of 700 to 800°C to reduce the external voltage needed for electrolysis.



## **Electrolysis of Pure Water**

An excess amount of energy in the form of overpotential (to overcome various activation barriers) is usually required for the electrolysis of pure water. This excess energy is extremely important because without it the process occurs very slowly and sometimes not at all. The limited self-ionization of water is also a reason for this. Moreover, the electrical conductivity of pure water is about one-millionth than that of seawater. In such cases, the efficiency of electrolysis can be increased by using a proper electrolyte such as a salt, an acid or a base along with electrocatalysts.

## 

## **Cell Potential or Voltage**

The minimum potential needed for the electrolysis process depends on their ability of the individual ions to absorb or release electrons. It is also sometimes described as decomposition potential or decomposition voltage which is the minimum voltage (difference in electrode potential) between anode and cathode of an electrolytic cell that enables electrolysis to occur.

The voltage at which electrolysis is thermodynamically preferred is the difference of the electrode potentials as calculated using the Nernst equation. Applying additional voltage, referred to as overpotential, can increase the rate of reaction and is often needed above the thermodynamic value. It is especially necessary for electrolysis reactions involving gases, such as oxygen, hydrogen or chlorine.

This ability is, measured as an electrode potential of the ions present in the electrolytic cell. The cell potential is the sum of the potential required for the reduction and oxidation reaction. The potential involved in various redox reactions is available in literature as standard reduction potential.

Reaction with positive redox cell potentials only will be feasible as per thermodynamic [Gibbs free energy](https://byjus.com/jee/gibbs-free-energy/) (or standard potential). Generally, the electrolysis is thermodynamically controlled.

In electrolysis, a potential equal to or slightly more than that, is, applied externally. The ions, which are stable and not reacting, are made to undergo reaction in the presence of externally applied potential. External potential hence makes an unfavourable reaction to take place. In electrolysis, chemical bonds connecting atoms are either made or broken and so, electrolysis involves the conversion of electrical energy into chemical energy.

## **Faraday’s Law of Electrolysis**

The amount of the redox reaction depends on the quantity of electricity flowing through the cell. Amount of reaction or the number of ions discharged is given by Faraday’s law of electrolysis. There are two laws.

Faraday’s first law can be summarized as;

. Here, m is the mass of the substance that has undergone change, E is the equivalent mass of the substance, ‘I’ is the current and ”t is the time in seconds of the passing of current.

Faraday’s second law compares the mass of different substances undergoing a change for the same current.

According to this second law,

Here, M and E are the changed mass and equivalent mass of the substances respectively.

## **Product of Electrolysis**

Electrolysis of only two ions (cation and anion) present in a single electrolyte is direct. Electrolysis will produce products present in the compound. When more than one cation and anions are present, each ion will compete for reduction and oxidations. Reactions with more positive redox potentials will be, reduced or oxidized, in preference, to others.

So, in spite of multiple redox couples present, only one can be reduced or oxidized. Sometimes the ions that are reduced or oxidized may depend on their relative amount. In other words, the redox reaction and electrolysis may become kinetically controlled. In such cases, the product of analysis may differ on the relative concentration of the various ions present in the electrolyte.

For example, electrolysis of aqueous sodium chloride may give different products-

1. Hydrogen and chlorine,
2. Hydrogen and oxygen and
3. Hydrogen, oxygen and chlorine.

[Nernst Equation](https://byjus.com/jee/nernst-equation/)

The Nernst equation provides a relation between the cell potential of an electrochemical cell, the standard cell potential, temperature, and the reaction quotient. Even under non-standard conditions, the cell potentials of electrochemical cells can be determined with the help of the Nernst equation.

The **Nernst equation is often used to calculate the cell potential** of an electrochemical cell at any given temperature, pressure, and reactant concentration. The equation was introduced by a German chemist named Walther Hermann Nernst.

## **Expression of Nernst Equation**

Nernst equation is an equation relating the capacity of an atom/ion to take up one or more electrons (reduction potential) measured at any conditions to that measured at standard conditions ([standard reduction potentials](https://byjus.com/chemistry/standard-electrode-potential/)) of 298K and one molar or one atmospheric pressure.

### Nernst Equation for Single Electrode Potential

Ecell = E0 – [RT/nF] ln Q

Where,

* Ecell = cell potential of the cell
* E0 = cell potential under standard conditions
* R = universal gas constant
* T = temperature
* n = number of electrons transferred in the redox reaction
* F = Faraday constant
* Q = reaction quotient

The calculation of single electrode reduction potential (Ered) from the standard single electrode reduction potential (E°red) for an atom/ion is given by the Nernst equation.

For a reduction reaction, Nernst equation for a single electrode reduction potential for a reduction reaction

Mn++ ne**–→**nM is;

Ered = EMn+/M = EoMn+/M – [2.303RT/nF] log [1/[Mn+]]

Where,

* R is the gas constant = 8.314 J/K Mole
* T = absolute temperature,
* n = number of mole of electron involved,
* F = 96487 (≈96500) coulomb/mole = charged carried by one mole of electrons.
* [Mn+] = active mass of the ions. For simplicity, it may be taken as equal to the molar concentration of the salt.

# Electrolytes

## **Electrolytes**

## An electrolyte is a substance that dissociates in water into charged particles called ions. Positively charged ions are called cations. Negatively charged ions are called anions. Simply, an electrolyte is a substance that can conduct an electric current when melted or dissolved in water.

### Electrolytes Explanation

An ionic compound for example, sodium chloride dissolved in water is called an electrolyte because it conducts electricity. Electrolytes are important body constituents because they,

* Conduct electricity, essential for muscle and nerve function.
* Exert osmotic pressure, keeping body fluids in their own compartments.
* Act as before to resist pH changes in body fluids.

Many biological compounds, for example, [carbohydrates](https://byjus.com/chemistry/classification-of-carbohydrates-and-its-structure/) are not ionic and therefore have no electrical properties when dissolved in water. Important electrolytes other than sodium and chloride include potassium, calcium, bicarbonate and phosphate.

## **List of Electrolytes**

### 1. Major Electrolytes Outside the Cell

Sodium and chloride, the major electrolytes in extracellular fluid, exert most of their influence outside the cell. Sodium concentration affects serum osmolality and extracellular fluid volume. Sodium also helps nerve and muscle cells interact. Chloride helps maintain osmotic pressure. Gastric mucosal cells need chloride to produce hydrochloric acid, which breaks down food into absorbable components.

Calcium and bicarbonate are two other electrolytes found in extracellular fluid. Calcium is the major cation involved in the structure and function of bones and teeth. Calcium is needed to

* stabilize the cell membrane and reduce its permeability to sodium transmit nerve impulses
* contract muscles
* coagulate blood
* form bone and teeth
* bicarbonate plays a vital role in acid base balance.

### 2. Major Electrolytes Inside the Cell

Potassium, phosphate and magnesium are among the most abundant electrolytes inside the cell.

**Potent potassium**

* Potassium plays an important role in
* cell excitability regulation
* nerve impulse conduction
* resting membrane potential
* muscle contraction and myocardial membrane responsiveness
* intracellular osmolality control

**Fundamental phosphorus**

The body contains phosphorus in the form of phosphate salts. Sometime the word phosphorus in the form of phosphate salts. Sometimes the words phosphorus and phosphate are used interchangeably. Phosphate is essential for energy metabolism. Combined with calcium, phosphate plays a key role in bone and tooth mineralization. It also helps maintain acid-base balance.

Magnesium acts as a catalyst for [enzyme reactions](https://byjus.com/chemistry/the-chemistry-behind-enzyme-catalysis/). It regulates neuromuscular contraction promotes normal functioning of the nervous and cardiovascular systems, and cardiovascular systems and aids in protein synthesis and sodium and potassium ion transportation.

## **Understanding Electrolytes**

Electrolytes help to regulate water distribution, govern acid base balance and transmit nerve impulses. They also contribute to energy generation and blood clotting. This table summarizes the functions of each of the body’s major electrolytes.

|  |  |
| --- | --- |
| Potassium (K) | * Main intracellular fluid (ICF) cation. * Regulate cell excitability. * Permeates cell membranes, thereby affecting the cells electrical status. * Helps to control ICF osmolality and consequently ICF osmotic pressure. |
| Magnesium (Mg) | * A leading ICF cation. * Contributes to many enzymatic and metabolic processes particularly protein synthesis. * Modifies nerve impulse transmission and skeletal muscle response. |
| Phosphorus (P) | * Main ICF anion * Promotes energy storage and carbohydrate, protein and fat metabolism. * Acts as a hydrogen buffer. |
| Sodium (Na) | * Main extracellular fluid (ECF) cation. * Helps govern normal ECF osmolality. * Helps maintain acid base balance * Activate nerve and muscle cells * Influence water distribution . |
| Chloride (Cl) | * Main ECF anion. * Helps maintain normal ECF osmolality. * Affects body pH. * Plays a vital role in maintaining acid base balance combines with hydrogen ions to produce hydrochloric acid. |
| Calcium (Ca) | * A major cation in teeth and bones found in fairly equal concentrations in ICF and ECF. * Also found in cell membranes, where it helps calls adhere to one another and maintain their shape. * Acts as an enzyme activator within cells. * Aids coagulation * Affects cell membrane permeability and firing level. |

#### **Electrochemical Cells**

Electrochemical cells are of three basic types. The electrolytic cell, the [galvanic cell](https://byjus.com/chemistry/galvanic-cell/), and the concentration cell. All such cells are similar in that they have four basic components. These components are

* The electrolyte is the current-carrying medium between the anode and cathode. It usually is homogeneous in an aqueous solution, but in moist soil, it may vary locally as to concentration or kind of dissolved chemicals.
* The anode is a metal or substance in contact with the electrolyte capable of conducting an electric current and corrodes by combining with chemicals in the electrolytes.
* The cathode is also a metal contacting the electrolyte. It is not corroded but receives protection against corrosion.
* The conductor extremely connects the anode and cathode and completes the circuit for current flow.

#### **Electrolyte Movement**

When cells die their contents spill into the extracellular area and upset the electrolyte balance. In this case, elevated levels of intracellular electrolytes are found in plasma.

Although electrolytes are generally concentrated in a specific compartment, they aren’t confined to these areas. Like fluids, they move around trying to maintain balance and electroneutrality.

#### **Electrolyte Balance**

Fluid and output acid-base balance hormone secretion and normal cell function can influence electrolyte balance. Because electrolytes and individually imbalances in one electrolyte can affect balance in others.

The body fluids contain a variety of dissolved chemicals that may be categorized as either nonelectrolytes or electrolytes. Nonelectrolytes are those compounds with covalent bonds that therefore do not dissociate when dissolved in water. Electrolytes are those compounds with at least one ionic bond that dissociate freely when dissolved in water.

Even though electrolytes exist inside and outside only the levels outside the cell in the bloodstream are measured. Although serum levels remain fairly stable throughout a person’s life span, understanding which levels are normal and which are abnormal is critical to reacting quickly and appropriately to a patient’s electrolyte imbalance.

## **Factors Affecting Electrolysis**

The factors that may affect the electrolysis are;

i) The nature of the electrode

ii) Nature and state of the electrolyte

iii) Nature and electrode potential of ions present in the electrolyte and

iv) Overvoltage at the electrodes.

**i) Nature and State of the Electrolyte**

Electrolysis involves the movement of ions towards the oppositely charged electrodes. Naturally, the electrolyte should have mobile ions. In solids, ions are in specific positions and cannot move at ordinary temperatures. Hence, solids are unsuitable for electrolysis.

For electrolysis, electrolyte should be in the liquid form- molten or in solution with a suitable polar solvent. Sodium chloride will undergo electrolysis in the molten state or in aqueous solution.

**ii) Nature and Electrode Potential of Ions Present in the Electrolyte**

* Electrolysis of electrolytes of two elemental ions is straight forward giving the two elements on electrolysis. Molten sodium chloride gives sodium atoms and chlorine molecule.
* Electrolysis of radical ions does not give the elemental atoms.
* Electrolytes containing more than one ionic compound depends on the relative redox potentials.
* Electrolysis of aqueous solutions of electrolytes. Water molecules also can undergo redox reactions and will compete with redox reactions of the electrolyte ions.
* Electrolysis of molten sodium chloride gives sodium and chlorine. But electrolysis of aqueous sodium chloride gives hydrogen and chlorine and not sodium.

**iii) Nature of the Electrode**

For the same electrolyte, the nature of the electrolyte may give different products. When aqueous copper sulphate solution is, electrolyzed, the following redox reactions are possible.

At cathode: Reduction at pH =7

Cu2+ (aq) + 2e**–** →Cu (s) E° = 0.34V and 2H2O + 2e**–**→H2 + 2OH**–** E° = -1.02V

At anode: Oxidation at pH = 7

Cu(s) →Cu2+ (aq) + 2e**–** E° = – 0.34V and 2H2O → O2(g) + 4H+ + 4e**–** E° = +1.4 V

At the cathode, out of the two electrodes reduction potential of copper ions is more positive than the reduction of water. So, irrespective of electrode, copper ions from the electrolyte will be reduced and deposited on the cathode, increasing its mass. But the reaction at anode depends on the electrode.

Electrolysis with inert electrodes like platinum, graphite, etc. Inert electrodes do not react with the electrolyte or the products and so does not undergo any changes. Since oxidation of water has more positive potential, oxygen will be evolved at the anode.

But, if the copper is used as an anode, it will react with the sulphate ion to retain the electrolyte concentration. So, there will not be any gas evolution. Instead, the anode mass slowly decreases going into the solution.

**iv) Overvoltage at the Electrodes**.

The redox potential of electrolyte ions decides the electrolysis reactions and products. Sometimes, redox potentials of some half-reactions during the electrolysis is more than the thermodynamic potentials. This excess voltage (over-voltage) of the half-reaction may make the reaction unfavourable and change the product of electrolysis.

In the hydrolysis of aqueous sodium chloride, at the anode, two oxidation reactions can take place. The reduction potential of water and chloride is +0.82V and 0.1.36V respectively.

2H2O→O2(g) + 4H+ + 4e**–** E° = -0.82 V

2Cl**–**→ Cl2 + 2e**–**E = – 1.36V

Oxidation of water being more positive is more feasible and so, the evolution of oxygen gas should happen at the anode. But, the evolution of oxygen from water has an overvoltage of -0.6V making the voltage for the oxidation of water as -1.42V. Chloride oxidation is more positive than the net voltage of water oxidation. Chloride is oxidized to chlorine at the anode. Chlorine is liberated and not oxygen because of overvoltage.

## **Electrolysis Applications**

Electrolysis, as stated above, is a process of converting the ions of a compound in a liquid state into their reduced or oxidized state by passing an electric current through the compound. Thus, electrolysis finds many applications both in experimental and industrial products. Some of the important ones are:

1) Determination of equivalent eight of substances.  
2) Metallurgy of alkali and alkaline earth metals.  
3) Purification of metals.  
4) Manufacture of pure gases.  
5) Manufacture of compounds like sodium hydroxide, sodium carbonate, potassium chlorate etc.  
6) Electroplating for corrosion resistance, ornaments etc.

We shall discuss the different applications of electrolysis in detail below.

### Determination of Equivalent Eight of Substances

We know Faraday’s Second Law states that the mass of substances deposited is proportional to their equivalent weight. Mass of any deposited substance can be, mathematically related as;

Equivalent mass of an unknown metal or substance can be calculated by passing a known current through the solutions and determining the mass of substances (M1 and M2) deposited in their respective cells. If the equivalent of one substance is known, the equivalent mass of the unknown substance can be calculated from the above equation.

### Electrolysis of Molten Salts

Metallurgy of alkali and alkaline earth and third group metals ores of metal are concentrated and converted mostly to oxides. Oxides are reduced with reducing agents such as carbon, aluminium etc. Since, alkali and alkali earth metals have the largest reduction potentials they cannot be, reduced by any other metals or their compounds.

The only way of isolation of alkali and alkali earth metals is to directly electrolyze their molten chlorides. Mixing with other halides like calcium chlorides reduces the melting point of pure halides.

### Electrorefining – Purification of Metals

Metals obtained after concentration and reduction of ores have a purity of about 90 -99%. An aqueous solution of the metal salt with the impure metal as anode and a pure metal as the cathode is electrolyzed. Pure metal, of more than 99% purity, deposits on the cathode and the impurities are collected at the bottom as mud. Copper and nickel are some examples of the metal purified by electrorefining.

### Electroplating

An object can be, coated to the required thickness with a select metal by electrolysis. The object to be, coated is, made cathode. An aqueous solution of the metal salt to be coated is the electrolyte. The same metal or any inert metal can be the anode. On electrolysis, metal ion from the electrolyte deposits on the object. The loss of metal ions in the solution will be, compensated if the same metal is made the anode.

The deposition can be, used to protect the metal from [corrosion](https://byjus.com/jee/corrosion/) are for making ornaments etc. Coating of iron with metals like zinc, lead, chromium, nickel improves the corrosion resistance of iron. Gold and silver coating on cheaper metals is used for making ornaments.

It is also used in electrochemical machining (ECM). Here an electrolytic cathode is used as a shaped tool for removing material by anodic oxidation from a workpiece. ECM technique is often used for deburring or for putting a permanent mark or logo on metal surfaces like tools or knives.

### Electro-forming

Electroforming is a process of making a replica of objects using electrolysis. The object to be replicated is pressed in wax to make a mould. Graphite powder is, coated uniformly to make it conducting. This is, used as a cathode and the salt of the metal to be deposited is taken as the electrolyte. After getting the required coating by electrolysis, wax and the graphite are, melted away.

### Manufacture of Pure Gases

Aqueous salts on hydrolysis yield different products depending on the relative concentrations of salt and water. Electrolysis of concentrated brine (sodium chloride) forms pure hydrogen and chlorine gases. Pure chlorine gas is, collected in the Chlor-alkali industries by the electrolysis of brine aqueous solution.

Pure hydrogen and oxygen are, obtained by hydrolysis of water in the presence of acid or base or inert salt of alkali and alkaline earth metals. Percentage of hydrogen for commercial use is manufactured by the electrolysis of water, worldwide.

Continuous electrolysis of water, removes all the normal hydrogen isotopes leaving the deuterium ions. The deuterium oxide leftover after electrolysis of normal water is ‘Heavy water’. Heavy water is used as a moderator in nuclear reactors producing electrical energy from nuclear reactions.

### Manufacture of Compounds

Compounds like sodium hydroxide, sodium hydrosulphite, potassium permanganate, potassium chlorate, ammonium per-sulphate, heavy water etc. are manufactured by electrolysis. Sodium hydroxide is a side product in the chloralkali industries preparing chlorine gas by the electrolysis of brine.

Potassium permanganate is obtained by the electrolysis of potassium manganite solution. Ammonium sulphate or ammonium bisulphate on electrolysis forms ammonium persulphate.

### Electrocrystallization

This is a specialized application of electrolysis. In this process, conductive crystals are grown on one of the electrodes from oxidized or reduced species that are generated in situ. This technique is popularly used to manufacture single crystals of low-dimensional electrical conductors such as linear chain compounds or charge-transfer salts.

1. Oxygen Production Technologies

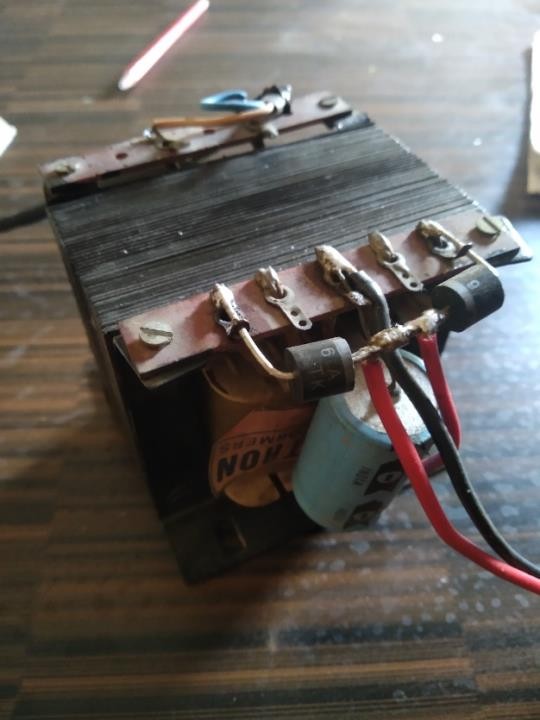
An air separation unit using a conventional , multi-column distillation process produces oxygen from compressed air at high recovery and purity . Cryogenic air separation is currently the most efficient and cost-effective technology for producing large quantities of oxygen, nitrogen, and or liquid products. The energy requirement of the latest technology is about 0.5 kWh/Nm3 -O2. Oxygen purity of cryogenic process can be higher than 99 vol. %. Because of high purity requirement, the oxygen for medical use is normally produced by cryogenic process. Neither technology excepting electrolysis is expected to challenge cryogenic air separation for large quantities production of oxygen especially at high purity.

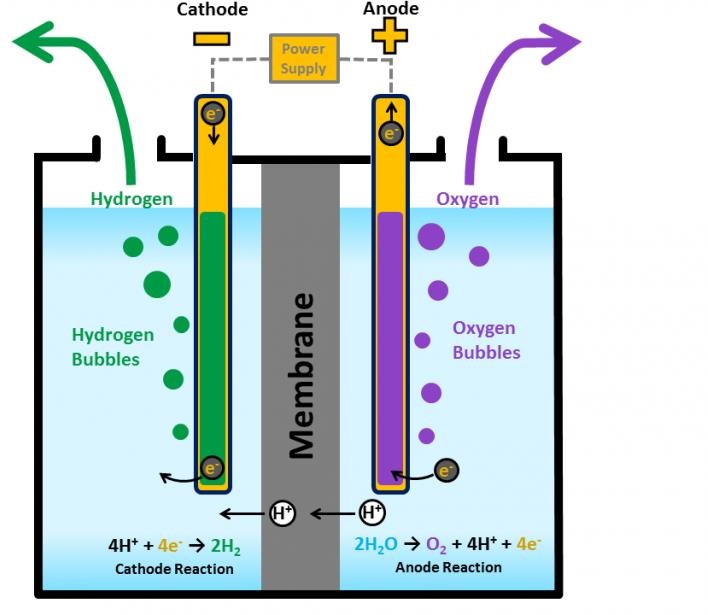
Because cryogenic air separation consists of five major processes, i.e. air compression, air pre-treatment, heat exchange, cryogenic separation and oxygen compression, it is utilized for large scale production larger than 8,000 Nm3 /h, and is not suitable for a small scale on-site oxygen production.

Adsorption process is based on the ability of some natural and synthetic materials such as zeolites to preferentially adsorb nitrogen. The regeneration of adsorbent is necessary and can be accomplished by heating the bed of zeolitic material (temperature swing adsorption, TSA) or reducing pressure in the bed (pressure swing adsorption, PSA). Because of the faster cycle time and simplified operation, PSA is usually used. Oxygen purity of adsorption process is typically 93 – 95 vol.%. The required energy in adsorption process is also about 0.5 kWh/Nm3 -O2. Adsorption process is used for smaller application as compared to cryogenic process.

Some non-cryogenic processes, i.e. chemical air separation process, membrane process and ion transport membrane, are also available.

Electrolysis is a promising option for hydrogen production from renewable resources. Electrolysis is the process of using electricity to split water into hydrogen and oxygen. This reaction takes place in a unit called an electrolyzer. Electrolyzers can range in size from small, appliance-size equipment that is well- suited for small-scale distributed hydrogen production to large-scale, central productionfacilities that could be tied directly to renewable or other non-greenhouse-gas-emitting forms of electricity production.





How Does it Work?

Like fuel cells, electrolyzers consist of an anode and a cathode separated by an electrolyte. Different electrolyzers function in slightly different ways, mainly due to the different type of electrolyte material involved.

POLYMER ELECTROLYTE MEMBRANE ELECTROLYZERS

In a polymer electrolyte membrane (PEM) electrolyzer, the electrolyte is a solid specialty plastic material.

* Water reacts at the anode to form oxygen and positively charged hydrogen ions (protons).
* The electrons flow through an external circuit and the hydrogen ions selectively move across the PEM to the cathode.
* At the cathode, hydrogen ions combine with electrons from the external circuit to form hydrogen gas. Anode Reaction: 2H2O → O2 + 4H+ + 4e- Cathode Reaction: 4H+ + 4e- → 2H2

ALKALINE ELECTROLYZERS

Alkaline electrolyzers operate via transport of hydroxide ions (OH-) through the electrolyte from the cathode to the anode with hydrogen being generated on the cathode side. Electrolyzers using a liquid alkaline solution of sodium or potassium hydroxide as the electrolyte have been commercially available for many years. Newer approaches using solid alkaline exchange membranes as the electrolyte are showing promise on the lab scale.

SOLID OXIDE ELECTROLYZERS

Solid oxide electrolyzers, which use a solid ceramic material as the electrolyte that selectively conducts negatively charged oxygen ions (O2-) at elevated temperatures, generate hydrogen in a slightly different way.

* Water at the cathode combines with electrons from the external circuit to form hydrogen gas and negatively charged oxygen ions.
* The oxygen ions pass through the solid ceramic membrane and react at the anode to form oxygen gas and generate electrons for the external circuit.

Solid oxide electrolyzers must operate at temperatures high enough for the solid oxide membranes to function properly (about 700°–800°C, compared to PEM electrolyzers, which operate at 70°–90°C, and commercial alkaline electrolyzers, which operate at 100°–150°C). The solid oxide electrolyzers can effectively use heat available at these elevated temperatures (from various sources, including nuclear energy) to decrease the amount of electrical energy needed to produce hydrogen from water.

Why Is This Pathway Being Considered?

Hydrogen produced via electrolysis can result in zero greenhouse gas emissions, depending on the source of the electricity used. The source of the required electricity—including its cost and efficiency, as well as emissions resulting from electricity generation—must be considered when evaluating the benefits and economic viability of hydrogen production via electrolysis. In many regions of the country, today's power grid is not ideal for providing the electricity required for electrolysis because of the greenhouse gases released and the amount of fuel required due to the low efficiency of the electricity generation process. Hydrogen production via electrolysis is being pursued for renewable (wind) and nuclear energy options. These pathways result in virtually zero greenhouse gas and criteria pollutant emissions.

It is important to note...

* Today's grid electricity is not the ideal source of electricity for electrolysis because most of the electricity is generated using technologies that result in greenhouse gas emissions and are energy intensive. Electricity generation using renewable or nuclear energy technologies, either separate from the grid, or as a growing portion of the grid mix, is a possible option to overcome these limitations for hydrogen production via electrolysis.
* The U.S. Department of Energy and others continue efforts to bring down the cost of renewable- based electricity production and develop more efficient coal-based electricity production with carbon capture, utilization, and storage. Wind-based electricity production, for example, is growing rapidly in the United States and globally.

Research Focuses On Overcoming Challenges

* Reducing the capital cost of the electrolyzer unit and the balance of the system, and improving energy efficiency for converting electricity to hydrogen.
* Integrating compression into the electrolyzer to avoid the cost of a separate hydrogen compressor needed to increase pressure for hydrogen storage.

1. Oxygen

# Oxygen

**Oxygen**



|  |  |
| --- | --- |
| Symbol | **O** |
| Atomic Number | **8** |
| Atomic Mass | **15.999 g.mol-1** |
| Discovered by | **Joseph Priestly in 1774** |

## **Chemical Properties of Oxygen**

|  |  |  |  |
| --- | --- | --- | --- |
| Group | **16** | Melting point | **-219 °c** |
| Period | **2** | Boiling point | **-183 °c** |
| Block | **p** | Density (g cm−3) | **0.001308** |
| Atomic number | **8** | Relative atomic mass | **15.999** |
| State at 20°C | **Gas** | Key isotopes | **16O** |
| Electron configuration | **[He]2s2****2p4** | CAS number | **7782-44-7** |
| ChemSpider ID | **140526** | ChemSpider is a free chemical structure database | |

## **What is Oxygen?**

Oxygen is a member of the chalcogen group on the periodic table. It is an essential element in the most of the combustion processes.It is one of the most abundant elements in the Earth’s crust.   
Dioxygen provides the energy released in combustion and aerobic cellular respiration and many major classes of organic molecules in living organisms contain oxygen atoms, such as proteins, nucleic acids, carbohydrates, and fats, as do the major constituent inorganic compounds of animal shells, teeth, and bone. Most of the mass of living organisms is oxygen as a component of water, the major constituent of lifeforms. Oxygen is continuously replenished in Earth's atmosphere by photosynthesis, which uses the energy of sunlight to produce oxygen from water and carbon dioxide. Oxygen is too chemically reactive to remain a free element in air without being continuously replenished by the photosynthetic action of living organisms. Another form (allotrope) of oxygen, ozone (O  
3), strongly absorbs ultraviolet UVB radiation and the high-altitude ozone layer helps protect the biosphere from ultraviolet radiation. However, ozone present at the surface is a byproduct of smog and thus a pollutant.

Oxygen was isolated by Michael Sendivogius before 1604, but it is commonly believed that the element was discovered independently by Carl Wilhelm Scheele, in Uppsala, in 1773 or earlier, and Joseph Priestley in Wiltshire, in 1774. Priority is often given for Priestley because his work was published first. Priestley, however, called oxygen "dephlogisticated air", and did not recognize it as a chemical element. The name *oxygen* was coined in 1777 by Antoine Lavoisier, who first recognized oxygen as a chemical element and correctly characterized the role it plays in combustion.

## **Uses of Oxygen**

* It is used in the production and manufacturing of glass and stone products, and in mining.
* Special oxygen chambers are used in case of high pressure to increase the partial pressure of oxygen around the patient.
* The primary applications of oxygen include melting, refining, and manufacture of steel along with other metals.

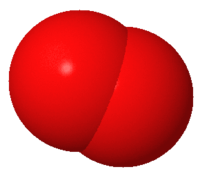
## **Physical Properties of Oxygen**

* The gas is colourless, odourless and insipid in a normal state. Liquid oxygen is slightly paramagnetic. It is reactive and forms oxides with every element except [helium](https://byjus.com/chemistry/helium/), neon, krypton, and argon. It is moderately soluble in water.
* Dioxygen is one of the common allotropes of oxygen.
* Trioxygen is the most reactive allotrope of oxygen that would cause damage to lung tissue. This allotrope is termed as ozone.

## **Other Important Information**

* O-16, O-17, and O-18 are the three naturally occurring stable isotopes of Oxygen.
* Oxygen is characterized by a paramagnetic property.

## Allotropes

[[](https://en.wikipedia.org/wiki/File:Oxygen_molecule.png)](https://en.wikipedia.org/wiki/File:Oxygen_molecule.png)

Space-filling model representation of dioxygen (O2) molecule

The common allotrope of elemental oxygen on Earth is called dioxygen, O2, the major part of the Earth's atmospheric oxygen (see Occurrence). O2 has a bond length of 121 pm and a bond energy of 498 kJ/mol which is smaller than the energy of other double bonds or pairs of single bonds in the biosphere and responsible for the exothermic reaction of O2 with any organic molecule.Due to its energy content, O2 is used by complex forms of life, such as animals, in cellular respiration. Other aspects of O  
2 are covered in the remainder of this article.

Trioxygen (O3) is usually known as ozone and is a very reactive allotrope of oxygen that is damaging to lung tissue. Ozone is produced in the upper atmosphere when O2 combines with atomic oxygen made by the splitting of O2 by ultraviolet (UV) radiation.Since ozone absorbs strongly in the UV region of the spectrum, the ozone layer of the upper atmosphere functions as a protective radiation shield for the planet.[[19]](https://en.wikipedia.org/wiki/Oxygen#cite_note-mellor-19) Near the Earth's surface, it is a pollutant formed as a by-product of automobile exhaust. At low earth orbit altitudes, sufficient atomic oxygen is present to cause corrosion of spacecraft.

The metastable molecule tetraoxygen (O4) was discovered in 2001,and was assumed to exist in one of the six phases of solid oxygen. It was proven in 2006 that this phase, created by pressurizing O2 to 20 GPa, is in fact a rhombohedral O8 cluster. This cluster has the potential to be a much more powerful oxidizer than either O2 or O3 and may therefore be used in rocket fuel. A metallic phase was discovered in 1990 when solid oxygen is subjected to a pressure of above 96 GPa and it was shown in 1998 that at very low temperatures, this phase becomes superconducting.

## Physical properties

Oxygen dissolves more readily in water than in nitrogen, and in freshwater more readily than in seawater. Water in equilibrium with air contains approximately 1 molecule of dissolved O2 for every 2 molecules of N2 (1:2), compared with an atmospheric ratio of approximately 1:4. The solubility of oxygen in water is temperature-dependent, and about twice as much (14.6 mg/L) dissolves at 0 °C than at 20 °C (7.6 mg/L).[[10]](https://en.wikipedia.org/wiki/Oxygen#cite_note-NBB299-10)[[47]](https://en.wikipedia.org/wiki/Oxygen#cite_note-50) At 25 °C and 1 [standard atmosphere](https://en.wikipedia.org/wiki/Atmosphere_(unit)) (101.3 [kPa](https://en.wikipedia.org/wiki/Pascal_(unit))) of air, freshwater can dissolve about 6.04 [milliliters](https://en.wikipedia.org/wiki/Litre) (mL) of oxygen per [liter](https://en.wikipedia.org/wiki/Liter), and [seawater](https://en.wikipedia.org/wiki/Seawater) contains about 4.95 mL per liter.[[48]](https://en.wikipedia.org/wiki/Oxygen#cite_note-51) At 5 °C the solubility increases to 9.0 mL (50% more than at 25 °C) per liter for freshwater and 7.2 mL (45% more) per liter for sea water.

|  |  |  |
| --- | --- | --- |
| **Oxygen gas dissolved in water at sea-level (milliliters per liter)** | | |
|  | **5 °C** | **25 °C** |
| Freshwater | 9.00 | 6.04 |
| Seawater | 7.20 | 4.95 |

Oxygen condenses at 90.20 [K](https://en.wikipedia.org/wiki/Kelvin) (−182.95 °C, −297.31 °F) and freezes at 54.36 K (−218.79 °C, −361.82 °F).[[49]](https://en.wikipedia.org/wiki/Oxygen#cite_note-52) Both [liquid](https://en.wikipedia.org/wiki/Liquid_oxygen) and [solid](https://en.wikipedia.org/wiki/Solid_oxygen) O2 are clear substances with a light [sky-blue](https://en.wikipedia.org/wiki/Diffuse_sky_radiation) color caused by absorption in the red (in contrast with the blue color of the sky, which is due to [Rayleigh scattering](https://en.wikipedia.org/wiki/Rayleigh_scattering) of blue light). High-purity liquid O2 is usually obtained by the [fractional distillation](https://en.wikipedia.org/wiki/Fractional_distillation) of liquefied air.[[50]](https://en.wikipedia.org/wiki/Oxygen#cite_note-53) Liquid oxygen may also be condensed from air using [liquid nitrogen](https://en.wikipedia.org/wiki/Liquid_nitrogen) as a coolant.

Liquid oxygen is a highly reactive substance and must be segregated from combustible materials.[[51]](https://en.wikipedia.org/wiki/Oxygen#cite_note-:0-54)

The spectroscopy of molecular oxygen is associated with the atmospheric processes of [aurora](https://en.wikipedia.org/wiki/Aurora) and [airglow](https://en.wikipedia.org/wiki/Airglow).[[52]](https://en.wikipedia.org/wiki/Oxygen#cite_note-Krupenie1972-55) The absorption in the [Herzberg continuum](https://en.wikipedia.org/w/index.php?title=Herzberg_continuum&action=edit&redlink=1) and [Schumann–Runge bands](https://en.wikipedia.org/wiki/Schumann%E2%80%93Runge_bands) in the ultraviolet produces atomic oxygen that is important in the chemistry of the middle atmosphere.[[53]](https://en.wikipedia.org/wiki/Oxygen#cite_note-BrasseurSolomon2006-56) Excited-state singlet molecular oxygen is responsible for red chemiluminescence in solution.

**Demand of Oxygen**

Oxygen is used in diverse applications covering many industries, including:

* + **Steel Manufacturing** To enrich air and increase combustion temperatures in the blast and open hearth furnaces; to raise steel temperatures and enhance recycling of scrap metal in electric arc furnaces and to replace coke as the combustible in steel making.
  + **Chemical Processing** To alter the structure of feedstocks through oxidation, producing nitric acid, ethylene oxide, propylene oxide, vinyl chloride monomer and other building block chemicals; and to increase capacity and destruction efficiency of waste incinerators.
  + **Pulp and Paper** To help manufacturers meet stringent environmental regulations in a variety of mill processes including delignification, bleaching, oxidative extraction, chemical recovery, white/black liquor oxidation and lime kiln enrichment.
  + **Metal Production** To replace or enrich air, increasing combustion temperatures in ferrous and non-ferrous metals production; to create a hot flame in high-temperature welding torches used in cutting and welding.
  + **Metal Fabrication** To support oxy-fuel cutting operations. Sometimes added in small quantities for shielding gases.
  + **Glass Manufacturing** To enhance combustion in glass furnaces and forehearths, reducing nitrogen oxide (NOx) emissions.
  + **Petroleum Recovery and Refining** To reduce viscosity and improve flow in oil and gas wells; to increase the capacity of fluid catalytic cracking plants as well as to facilitate the use of heavier feedstocks and to reduce sulfur emissions in refineries.
  + **Health Services** To resuscitate or, in combination with other gases, to anesthetize but also essential to life-support systems used in emergencies or long-term treatment of patients with respiratory disorders.
  + **Utilities** To convert coal to electricity for power generation.

#### About Medical Oxygen

Uptake of O2 from the air is the essential purpose of respiration, so oxygen supplementation is used in medicine. Treatment not only increases oxygen levels in the patient's blood, but has the secondary effect of decreasing resistance to blood flow in many types of diseased lungs, easing work load on the heart. Oxygen therapy is used to treat emphysema, pneumonia, some heart disorders (congestive heart failure), some disorders that cause increased pulmonary artery pressure, and any disease that impairs the body's ability to take up and use gaseous oxygen.

Treatments are flexible enough to be used in hospitals, the patient's home, or increasingly by portable devices. Oxygen tents were once commonly used in oxygen supplementation, but have since been replaced mostly by the use of oxygen masks or nasal cannulas[

Hyperbaric (high-pressure) medicine uses special oxygen chambers to increase the partial pressure of O  
2 around the patient and, when needed, the medical staff. Carbon monoxide poisoning, gas gangrene, and decompression sickness (the 'bends') are sometimes addressed with this therapy. Increased O  
2 concentration in the lungs helps to displace carbon monoxide from the heme group of hemoglobin. Oxygen gas is poisonous to the anaerobic bacteria that cause gas gangrene, so increasing its partial pressure helps kill them. Decompression sickness occurs in divers who decompress too quickly after a dive, resulting in bubbles of inert gas, mostly nitrogen and helium, forming in the blood. Increasing the pressure of O  
2 as soon as possible helps to redissolve the bubbles back into the blood so that these excess gasses can be exhaled naturally through the lungs. Normobaric oxygen administration at the highest available concentration is frequently used as first aid for any diving injury that may involve inert gas bubble formation in the tissues. There is epidemiological support for its use from a statistical study of cases recorded in a long term database.In medicine, oxygen has a number of uses. It is sometimes offered therapeutically, to patients who are having difficulty breathing. It is also used in anesthesia mixtures, ensuring that the patient gets a consistent supply of oxygen while unconscious. Although pure oxygen is used medicinally and recreationally, as it brings about a state of mild euphoria, it is potentially dangerous. In high-pressure environments, oxygen toxicity can damage the lungs, often quite severely. Depending on the pressure, symptoms may emerge right away, or they may take several hours to manifest, at which point it can be too late.

### Life support and recreational use

[](https://en.wikipedia.org/wiki/File:STS057-89-067_-_Wisoff_on_the_Arm_(Retouched).jpg)

Low pressure pure O2 is used in space suits.

An application of O2 as a low-pressure breathing gas is in modern space suits, which surround their occupant's body with the breathing gas. These devices use nearly pure oxygen at about one-third normal pressure, resulting in a normal blood partial pressure of O2. This trade-off of higher oxygen concentration for lower pressure is needed to maintain suit flexibility.

Scuba and surface-supplied underwater divers and submariners also rely on artificially delivered O2. Submarines, submersibles and atmospheric diving suits usually operate at normal atmospheric pressure. Breathing air is scrubbed of carbon dioxide by chemical extraction and oxygen is replaced to maintain a constant partial pressure. Ambient pressure divers breathe air or gas mixtures with an oxygen fraction suited to the operating depth. Pure or nearly pure O2 use in diving at pressures higher than atmospheric is usually limited to rebreathers, or decompression at relatively shallow depths (~6 meters depth, or less), or medical treatment in recompression chambers at pressures up to 2.8 bar, where acute oxygen toxicity can be managed without the risk of drowning. Deeper diving requires significant dilution of O2 with other gases, such as nitrogen or helium, to prevent oxygen toxicity.

People who climb mountains or fly in non-pressurized fixed-wing aircraft sometimes have supplemental O2 supplies. Pressurized commercial airplanes have an emergency supply of O2 automatically supplied to the passengers in case of cabin depressurization. Sudden cabin pressure loss activates chemical oxygen generators above each seat, causing oxygen masks to drop. Pulling on the masks "to start the flow of oxygen" as cabin safety instructions dictate, forces iron filings into the sodium chlorate inside the canister. A steady stream of oxygen gas is then produced by the exothermic reaction.

Oxygen, as a mild euphoric, has a history of recreational use in oxygen bars and in sports. Oxygen bars are establishments found in the United States since the late 1990s that offer higher than normal O  
2 exposure for a minimal fee. Professional athletes, especially in American football, sometimes go off-field between plays to don oxygen masks to boost performance. The pharmacological effect is doubted; a placebo effect is a more likely explanation.Available studies support a performance boost from oxygen enriched mixtures only if it is inhaled *during* aerobic exercise.

Other recreational uses that do not involve breathing include pyrotechnic applications, such as George Goble's five-second ignition of barbecue grills.

### Industrial

[](https://en.wikipedia.org/wiki/File:Clabecq_JPG01.jpg)

Most commercially produced O2 is used to smelt and/or decarburize iron.

Smelting of iron ore into steel consumes 55% of commercially produced oxygen. In this process, O2 is injected through a high-pressure lance into molten iron, which removes sulfur impurities and excess [carbon](https://en.wikipedia.org/wiki/Carbon) as the respective oxides, SO2 and CO2. The reactions are [exothermic](https://en.wikipedia.org/wiki/Exothermic_reaction), so the temperature increases to 1,700 °[C](https://en.wikipedia.org/wiki/Celsius).[[66]](https://en.wikipedia.org/wiki/Oxygen#cite_note-NBB301-70)

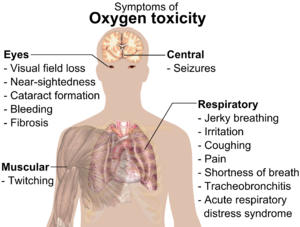
Another 25% of commercially produced oxygen is used by the chemical industry.[[66]](https://en.wikipedia.org/wiki/Oxygen#cite_note-NBB301-70) [Ethylene](https://en.wikipedia.org/wiki/Ethylene) is reacted with O2 to create [ethylene oxide](https://en.wikipedia.org/wiki/Ethylene_oxide), which, in turn, is converted into [ethylene glycol](https://en.wikipedia.org/wiki/Ethylene_glycol); the primary feeder material used to manufacture a host of products, including [antifreeze](https://en.wikipedia.org/wiki/Antifreeze) and [polyester](https://en.wikipedia.org/wiki/Polyester) polymers (the precursors of many [plastics](https://en.wikipedia.org/wiki/Plastic) and [fabrics](https://en.wikipedia.org/wiki/Fabric)). Large quantities of oxygen or air is used in oxy-cracking processand for the production of acrylic acid, diformyl-furane, and benzylic acid. On the other hand, the electrochemical synthesis of hydrogen peroxide from oxygen is a promising technology to replace the currently used hydroquinone-process. Last but not least, catalytic oxidation is used in afterburners to get rid of hazardous gases.

Most of the remaining 20% of commercially produced oxygen is used in medical applications, [metal cutting and welding](https://en.wikipedia.org/wiki/Gas_welding), as an oxidizer in [rocket fuel](https://en.wikipedia.org/wiki/Rocket_fuel), and in [water treatment](https://en.wikipedia.org/wiki/Water_treatment).]Oxygen is used in [oxyacetylene welding](https://en.wikipedia.org/wiki/Oxyacetylene_welding), burning [acetylene](https://en.wikipedia.org/wiki/Acetylene) with O2 to produce a very hot flame. In this process, metal up to 60 cm (24 in) thick is first heated with a small oxy-acetylene flame and then quickly cut by a large stream of O2.

## Safety and precautions

The [NFPA 704](https://en.wikipedia.org/wiki/NFPA_704) standard rates compressed oxygen gas as nonhazardous to health, nonflammable and nonreactive, but an oxidizer. Refrigerated liquid oxygen (LOX) is given a health hazard rating of 3 (for increased risk of [hyperoxia](https://en.wikipedia.org/wiki/Hyperoxia) from condensed vapors, and for hazards common to cryogenic liquids such as frostbite), and all other ratings are the same as the compressed gas form.[[132]](https://en.wikipedia.org/wiki/Oxygen#cite_note-nfpa-141)

## Toxicity

[](https://en.wikipedia.org/wiki/File:Symptoms_of_oxygen_toxicity.png)

Main symptoms of oxygen toxicity

Oxygen gas (O2) can be [toxic](https://en.wikipedia.org/wiki/Oxygen_toxicity) at elevated [partial pressures](https://en.wikipedia.org/wiki/Partial_pressure), leading to [convulsions](https://en.wikipedia.org/wiki/Convulsion) and other health problems. Oxygen toxicity usually begins to occur at partial pressures more than 50 kilo[pascals](https://en.wikipedia.org/wiki/Pascal_(unit)) (kPa), equal to about 50% oxygen composition at standard pressure or 2.5 times the normal sea-level O2 partial pressure of about 21 kPa. This is not a problem except for patients on [mechanical ventilators](https://en.wikipedia.org/wiki/Mechanical_ventilator), since gas supplied through [oxygen masks](https://en.wikipedia.org/wiki/Oxygen_mask) in medical applications is typically composed of only 30–50% O2 by volume (about 30 kPa at standard pressure).[[10]](https://en.wikipedia.org/wiki/Oxygen#cite_note-NBB299-10)

At one time, [premature babies](https://en.wikipedia.org/wiki/Premature_birth) were placed in incubators containing O2-rich air, but this practice was discontinued after some babies were blinded by the oxygen content being too high.

Breathing pure O2 in space applications, such as in some modern space suits, or in early spacecraft such as [Apollo](https://en.wikipedia.org/wiki/Apollo_spacecraft), causes no damage due to the low total pressures used.[[109]](https://en.wikipedia.org/wiki/Oxygen#cite_note-pmid11541018-116)[[135]](https://en.wikipedia.org/wiki/Oxygen#cite_note-145) In the case of spacesuits, the O2 partial pressure in the breathing gas is, in general, about 30 kPa (1.4 times normal), and the resulting O2 partial pressure in the astronaut's arterial blood is only marginally more than normal sea-level O2 partial pressure.[[136]](https://en.wikipedia.org/wiki/Oxygen#cite_note-146)

Oxygen toxicity to the lungs and [central nervous system](https://en.wikipedia.org/wiki/Central_nervous_system) can also occur in deep [scuba diving](https://en.wikipedia.org/wiki/Scuba_diving) and [surface supplied diving](https://en.wikipedia.org/wiki/Surface_supplied_diving). Prolonged breathing of an air mixture with an O2 partial pressure more than 60 kPa can eventually lead to permanent [pulmonary fibrosis](https://en.wikipedia.org/wiki/Pulmonary_fibrosis).[[137]](https://en.wikipedia.org/wiki/Oxygen#cite_note-BMJ-147) Exposure to an O2 partial pressures greater than 160 kPa (about 1.6 atm) may lead to convulsions (normally fatal for divers). Acute oxygen toxicity (causing seizures, its most feared effect for divers) can occur by breathing an air mixture with 21% O2 at 66 m (217 ft) or more of depth; the same thing can occur by breathing 100% O2 at only 6 m (20 ft).

# Combustion and other hazards

[](https://en.wikipedia.org/wiki/File:Apollo_1_fire.jpg)

The interior of the [Apollo 1](https://en.wikipedia.org/wiki/Apollo_1) Command Module. Pure O2 at higher than normal pressure and a spark led to a fire and the loss of the [Apollo 1](https://en.wikipedia.org/wiki/Apollo_1) crew.

Highly concentrated sources of oxygen promote rapid combustion. [Fire](https://en.wikipedia.org/wiki/Fire) and [explosion](https://en.wikipedia.org/wiki/Explosion) hazards exist when concentrated oxidants and [fuels](https://en.wikipedia.org/wiki/Fuel) are brought into close proximity; an ignition event, such as heat or a spark, is needed to trigger combustion.[[4]](https://en.wikipedia.org/wiki/Oxygen#cite_note-Weiss2008-4)[[141]](https://en.wikipedia.org/wiki/Oxygen#cite_note-astm-tpt-151) Oxygen is the oxidant, not the fuel, but nevertheless the source of most of the chemical energy released in combustion.[[4]](https://en.wikipedia.org/wiki/Oxygen#cite_note-Weiss2008-4)[[39]](https://en.wikipedia.org/wiki/Oxygen#cite_note-Schmidt-Rohr2015-42)

Concentrated O  
2 will allow combustion to proceed rapidly and energetically.[[141]](https://en.wikipedia.org/wiki/Oxygen#cite_note-astm-tpt-151) [Steel](https://en.wikipedia.org/wiki/Steel) pipes and storage vessels used to store and transmit both gaseous and [liquid oxygen](https://en.wikipedia.org/wiki/Liquid_oxygen) will act as a fuel; and therefore the design and manufacture of O  
2 systems requires special training to ensure that ignition sources are minimized.[[141]](https://en.wikipedia.org/wiki/Oxygen#cite_note-astm-tpt-151) The fire that killed the [Apollo 1](https://en.wikipedia.org/wiki/Apollo_1) crew in a launch pad test spread so rapidly because the capsule was pressurized with pure O  
2 but at slightly more than atmospheric pressure, instead of the 1⁄3 normal pressure that would be used in a mission.[[k]](https://en.wikipedia.org/wiki/Oxygen#cite_note-153)[[143]](https://en.wikipedia.org/wiki/Oxygen#cite_note-chiles-154)

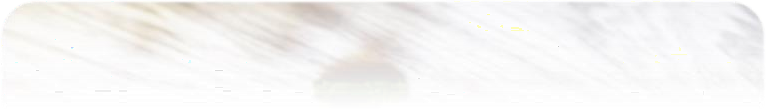
Liquid oxygen spills, if allowed to soak into organic matter, such as [wood](https://en.wikipedia.org/wiki/Wood), [petrochemicals](https://en.wikipedia.org/wiki/Petrochemical), and [asphalt](https://en.wikipedia.org/wiki/Asphalt) can cause these materials to [detonate](https://en.wikipedia.org/wiki/Detonation) unpredictably on subsequent mechanical impact.

#### Oxygen Applications

#### Some of the major applications of oxygen include the following:

* It is used in oxy-acetylene torch for cutting and welding metals
* It is used to remove carbon impurities from the steel during steel production
* A mixture of liquid oxygen and powdered charcoal is used as an explosive
* It is used as an oxidant for rocket fuel
* It is used in large quantities for the synthesis of ethylene oxide, methanol and ammonia.
* Dissolved oxygen is essential for the life of fish.

## Hydrogen



**Hydrogen** is the [chemical element](https://en.wikipedia.org/wiki/Chemical_element) with the [symbol](https://en.wikipedia.org/wiki/Symbol_(chemistry)) **H** and [atomic number](https://en.wikipedia.org/wiki/Atomic_number) 1. Hydrogen is the lightest element. At [standard conditions](https://en.wikipedia.org/wiki/Standard_temperature_and_pressure) hydrogen is a [gas](https://en.wikipedia.org/wiki/Gas) of [diatomic molecules](https://en.wikipedia.org/wiki/Diatomic_molecule) having the [formula](https://en.wikipedia.org/wiki/Chemical_formula) **H2**. It is [colorless](https://en.wikipedia.org/wiki/Transparency_(optics)), [odorless](https://en.wikipedia.org/wiki/Sense_of_smell), [tasteless](https://en.wikipedia.org/wiki/Taste), non-toxic, and highly [combustible](https://en.wikipedia.org/wiki/Combustible). Hydrogen is the [most abundant](https://en.wikipedia.org/wiki/Abundance_of_the_chemical_elements) chemical substance in the [universe](https://en.wikipedia.org/wiki/Universe), constituting roughly 75% of all [normal](https://en.wikipedia.org/wiki/Baryon) [matter](https://en.wikipedia.org/wiki/Matter). [Stars](https://en.wikipedia.org/wiki/Star) such as the [Sun](https://en.wikipedia.org/wiki/Sun) are mainly composed of hydrogen in the [plasma state](https://en.wikipedia.org/wiki/Plasma_state). Most of the hydrogen on Earth exists in [molecular forms](https://en.wikipedia.org/wiki/Molecular_geometry) such as [water](https://en.wikipedia.org/wiki/Water) and [organic compounds](https://en.wikipedia.org/wiki/Organic_compound). For the most common [isotope](https://en.wikipedia.org/wiki/Isotope) of hydrogen (symbol 1H) each [atom](https://en.wikipedia.org/wiki/Atom) has one [proton](https://en.wikipedia.org/wiki/Proton), one [electron](https://en.wikipedia.org/wiki/Electron), and no [neutrons](https://en.wikipedia.org/wiki/Neutron).

In the early [universe](https://en.wikipedia.org/wiki/Universe), the formation of protons, the nuclei of hydrogen, occurred during the first second after the [Big Bang](https://en.wikipedia.org/wiki/Big_Bang). The emergence of neutral hydrogen atoms throughout the universe occurred about 370,000 years later during the [recombination epoch](https://en.wikipedia.org/wiki/Recombination_(cosmology)), when the [plasma](https://en.wikipedia.org/wiki/Plasma_(physics)) had cooled enough for [electrons](https://en.wikipedia.org/wiki/Electrons) to remain bound to protons.[[10]](https://en.wikipedia.org/wiki/Hydrogen#cite_note-11)

Hydrogen is [nonmetallic](https://en.wikipedia.org/wiki/Nonmetallic), except at extremely high pressures, and readily forms a single [covalent bond](https://en.wikipedia.org/wiki/Covalent_bond) with most nonmetallic elements, forming compounds such as [water](https://en.wikipedia.org/wiki/Water) and nearly all [organic compounds](https://en.wikipedia.org/wiki/Organic_compound). Hydrogen plays a particularly important role in [acid–base reactions](https://en.wikipedia.org/wiki/Acid%E2%80%93base_reaction) because these reactions usually involve the exchange of protons between soluble molecules. In [ionic compounds](https://en.wikipedia.org/wiki/Ionic_compound), hydrogen can take the form of a negative charge (i.e., [anion](https://en.wikipedia.org/wiki/Anion)) where it is known as a [hydride](https://en.wikipedia.org/wiki/Hydride), or as a positively charged (i.e., [cation](https://en.wikipedia.org/wiki/Cation)) [species](https://en.wikipedia.org/wiki/Chemical_species) denoted by the symbol H+. The H+ cation is simply a [proton](https://en.wikipedia.org/wiki/Proton) (symbol **p**) but its behavior in [aqueous solutions](https://en.wikipedia.org/wiki/Aqueous_solution) and in [ionic compounds](https://en.wikipedia.org/wiki/Ionic_compound) involves [screening](https://en.wikipedia.org/wiki/Electric-field_screening) of its [electric charge](https://en.wikipedia.org/wiki/Electric_charge) by nearby [polar](https://en.wikipedia.org/wiki/Chemical_polarity) molecules or anions. Because hydrogen is the only neutral atom for which the [Schrödinger equation](https://en.wikipedia.org/wiki/Schr%C3%B6dinger_equation) can be solved analytically, the study of its energetics and chemical bonding has played a key role in the development of [quantum mechanics](https://en.wikipedia.org/wiki/Quantum_mechanics).

Hydrogen gas was first artificially produced in the early 16th century by the reaction of acids on metals. In 1766–1781, [Henry Cavendish](https://en.wikipedia.org/wiki/Henry_Cavendish) was the first to recognize that hydrogen gas was a discrete substance, and that it produces water when burned, the property for which it was later named: in Greek, hydrogen means "water-former".

[Industrial production](https://en.wikipedia.org/wiki/Hydrogen_production) is mainly from [steam reforming](https://en.wikipedia.org/wiki/Steam_reforming) of [natural gas](https://en.wikipedia.org/wiki/Natural_gas), oil reforming, or [coal gasification](https://en.wikipedia.org/wiki/Coal_gasification). A small percentage is also produced using more energy-intensive methods such as the [electrolysis of water](https://en.wikipedia.org/wiki/Electrolysis_of_water). Most hydrogen is used near the site of its production, the two largest uses being [fossil fuel](https://en.wikipedia.org/wiki/Fossil_fuel) processing (e.g., [hydrocracking](https://en.wikipedia.org/wiki/Hydrocracking)) and [ammonia](https://en.wikipedia.org/wiki/Ammonia) production, mostly for the fertilizer market. Hydrogen is problematic in [metallurgy](https://en.wikipedia.org/wiki/Metallurgy) because it can [embrittle](https://en.wikipedia.org/wiki/Hydrogen_embrittlement) many metals, complicating the design of pipelines and [storage tanks](https://en.wikipedia.org/wiki/Hydrogen_storage).

## **Properties**

# Combustion

**0:29**

Combustion of hydrogen with the oxygen in the air. When the bottom cap is removed, allowing air to enter at the bottom, the hydrogen in the container rises out of top and burns as it mixes with the air.

[](https://en.wikipedia.org/wiki/File:Shuttle_Main_Engine_Test_Firing_cropped_edited_and_reduced.jpg)

The [Space Shuttle Main Engine](https://en.wikipedia.org/wiki/Space_Shuttle_Main_Engine) burnt hydrogen with oxygen, producing a nearly invisible flame at full thrust.

Hydrogen gas (**dihydrogen** or molecular hydrogen) is highly flammable:

2 H2(g) + O2(g) → 2 H2O(l) + 572 kJ (286 kJ/mol)

The [enthalpy of combustion](https://en.wikipedia.org/wiki/Enthalpy_of_combustion) is −286 kJ/mol.

Hydrogen gas forms explosive mixtures with air in concentrations from 4–74% and with chlorine at 5–95%. The explosive reactions may be triggered by spark, heat, or sunlight. The hydrogen [autoignition temperature](https://en.wikipedia.org/wiki/Autoignition_temperature), the temperature of spontaneous ignition in air, is 500 °C (932 °F).

#### Flame

Pure [hydrogen-oxygen](https://en.wikipedia.org/wiki/Oxyhydrogen) flames emit [ultraviolet](https://en.wikipedia.org/wiki/Ultraviolet) light and with high oxygen mix are nearly invisible to the naked eye, as illustrated by the faint plume of the [Space Shuttle Main Engine](https://en.wikipedia.org/wiki/Space_Shuttle_Main_Engine), compared to the highly visible plume of a [Space Shuttle Solid Rocket Booster](https://en.wikipedia.org/wiki/Space_Shuttle_Solid_Rocket_Booster), which uses an [ammonium perchlorate composite](https://en.wikipedia.org/wiki/Ammonium_perchlorate_composite_propellant). The detection of a burning hydrogen leak may require a [flame detector](https://en.wikipedia.org/wiki/Flame_detector); such leaks can be very dangerous. Hydrogen flames in other conditions are blue, resembling blue natural gas flames.[[21]](https://en.wikipedia.org/wiki/Hydrogen#cite_note-23) The [destruction of the Hindenburg airship](https://en.wikipedia.org/wiki/Hindenburg_disaster) was a notorious example of hydrogen combustion and the cause is still debated. The visible flames in the photographs were the result of carbon compounds in the airship skin burning.

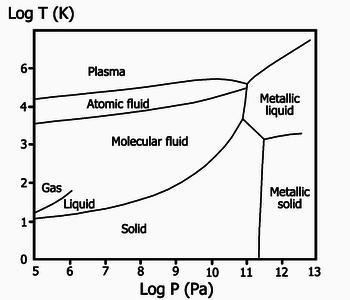
#### Reactants

H2 is unreactive compared to diatomic elements such as [halogens](https://en.wikipedia.org/wiki/Halogens) or oxygen. The thermodynamic basis of this low reactivity is the very strong H-H bond, with a [bond dissociation energy](https://en.wikipedia.org/wiki/Bond_dissociation_energy) of 435.7 kJ/mol.The kinetic basis of the low reactivity is the nonpolar nature of H2 and its weak polarizability. It spontaneously reacts with [chlorine](https://en.wikipedia.org/wiki/Chlorine) and [fluorine](https://en.wikipedia.org/wiki/Fluorine) to form [hydrogen chloride](https://en.wikipedia.org/wiki/Hydrogen_chloride) and [hydrogen fluoride](https://en.wikipedia.org/wiki/Hydrogen_fluoride), respectively. The reactivity of H2 is strongly affected by the presence of metal catalysts. Thus, while mixtures of H2 with O2 or air combust readily when heated to at least 500 C by a spark or flame, they do not react at room temperature in the absence of a catalyst.

### Phases

[](https://en.wikipedia.org/wiki/File:Hydrogen_ampoule.jpg)

Hydrogen gas is colorless and transparent, here contained in a glass [ampoule](https://en.wikipedia.org/wiki/Ampoule).

[](https://en.wikipedia.org/wiki/File:Phase_diagram_of_hydrogen.png)

[Phase diagram](https://en.wikipedia.org/wiki/Phase_diagram) of hydrogen. The temperature and pressure scales are [logarithmic](https://en.wikipedia.org/wiki/Logarithmic_scale), so one unit corresponds to a 10x change. The left edge corresponds to 105 Pa, which is about [atmospheric pressure](https://en.wikipedia.org/wiki/Atmospheric_pressure).

* [Gaseous](https://en.wikipedia.org/wiki/Gas) hydrogen
* [Liquid hydrogen](https://en.wikipedia.org/wiki/Liquid_hydrogen)
* [Slush hydrogen](https://en.wikipedia.org/wiki/Slush_hydrogen)
* [Solid hydrogen](https://en.wikipedia.org/wiki/Solid_hydrogen)
* [Metallic hydrogen](https://en.wikipedia.org/wiki/Metallic_hydrogen)
* [Plasma](https://en.wikipedia.org/wiki/Plasma_(physics)) hydrogen

## **States**

Throughout the universe, hydrogen is mostly found in the [atomic](https://en.wikipedia.org/wiki/Atom) and [plasma](https://en.wikipedia.org/wiki/Plasma_(physics)) states, with properties quite distinct from those of molecular hydrogen. As a plasma, hydrogen's electron and proton are not bound together, resulting in very high electrical conductivity and high emissivity (producing the light from the Sun and other stars). The charged particles are highly influenced by magnetic and electric fields. For example, in the [solar wind](https://en.wikipedia.org/wiki/Solar_wind) they interact with the Earth's [magnetosphere](https://en.wikipedia.org/wiki/Magnetosphere) giving rise to [Birkeland currents](https://en.wikipedia.org/wiki/Birkeland_current" \o "Birkeland current) and the [aurora](https://en.wikipedia.org/wiki/Aurora_(phenomenon)).

Hydrogen is found in the neutral atomic state in the [interstellar medium](https://en.wikipedia.org/wiki/Interstellar_medium) because the atoms seldom collide and combine. They are the source of the [21-cm hydrogen line](https://en.wikipedia.org/wiki/Hydrogen_line) at 1420 MHz that is detected in order to probe primordial hydrogen. The large amount of neutral hydrogen found in the [damped Lyman-alpha systems](https://en.wikipedia.org/wiki/Damped_Lyman-alpha_system) is thought to dominate the [cosmological](https://en.wikipedia.org/wiki/Physical_cosmology) [baryonic](https://en.wikipedia.org/wiki/Baryon) density of the universe up to a [redshift](https://en.wikipedia.org/wiki/Redshift) of *z* = 4.

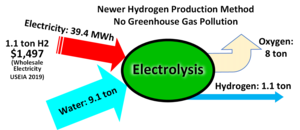
Under ordinary conditions on Earth, elemental hydrogen exists as the diatomic gas, H2. Hydrogen gas is very rare in the Earth's atmosphere (1 [ppm](https://en.wikipedia.org/wiki/Part_per_million) by volume) because of its light weight, which enables it to [escape from the atmosphere](https://en.wikipedia.org/wiki/Atmospheric_escape) more rapidly than heavier gases. However, hydrogen is the third most abundant element on the Earth's surface, mostly in the form of [chemical compounds](https://en.wikipedia.org/wiki/Chemical_compound) such as [hydrocarbons](https://en.wikipedia.org/wiki/Hydrocarbon) and water.

A molecular form called [protonated molecular hydrogen](https://en.wikipedia.org/wiki/Protonated_molecular_hydrogen) (H+  
3) is found in the interstellar medium, where it is generated by ionization of molecular hydrogen from [cosmic rays](https://en.wikipedia.org/wiki/Cosmic_ray). This ion has also been observed in the upper atmosphere of the planet [Jupiter](https://en.wikipedia.org/wiki/Jupiter). The ion is relatively stable in the environment of outer space due to the low temperature and density. H+3 is one of the most abundant ions in the universe, and it plays a notable role in the chemistry of the interstellar medium. Neutral [triatomic hydrogen](https://en.wikipedia.org/wiki/Triatomic_hydrogen) H3 can exist only in an excited form and is unstable. By contrast, the positive [hydrogen molecular ion](https://en.wikipedia.org/wiki/Hydrogen_molecular_ion) (H+2) is a rare molecule in the universe.

## **Production**

H2 is produced in chemistry and biology laboratories, often as a by-product of other reactions; in industry for the [hydrogenation](https://en.wikipedia.org/wiki/Hydrogenation) of [unsaturated](https://en.wikipedia.org/wiki/Saturated_and_unsaturated_compounds) substrates; and in nature as a means of expelling [reducing](https://en.wikipedia.org/wiki/Redox) equivalents in biochemical reactions.

### Water electrolysis

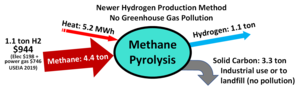
[](https://en.wikipedia.org/wiki/File:Hydrogen_production_via_Electrolysis.png)

Illustrating inputs and outputs of simple electrolysis of water production of hydrogen

The [electrolysis of water](https://en.wikipedia.org/wiki/Electrolysis_of_water) is a simple method of producing hydrogen. A current is run through the water, and gaseous oxygen forms at the [anode](https://en.wikipedia.org/wiki/Anode) while gaseous hydrogen forms at the [cathode](https://en.wikipedia.org/wiki/Cathode). Typically the cathode is made from platinum or another inert metal when producing hydrogen for storage. If, however, the gas is to be burnt on site, oxygen is desirable to assist the combustion, and so both electrodes would be made from inert metals. (Iron, for instance, would oxidize, and thus decrease the amount of oxygen given off.) The theoretical maximum efficiency (electricity used vs. energetic value of hydrogen produced) is in the range 88–94%.

2 H2O(l) → 2 H2(g) + O2(g)

### Methane pyrolysis

[](https://en.wikipedia.org/wiki/File:Methane_Pyrolysis-1.png)

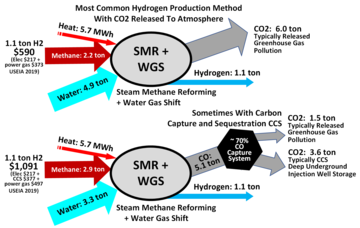
Illustrating inputs and outputs of [methane pyrolysis](https://en.wikipedia.org/wiki/Methane_pyrolysis), a process to produce hydrogen

Hydrogen production using natural gas methane [pyrolysis](https://en.wikipedia.org/wiki/Pyrolysis) is a one-step process that produces no [greenhouse gases](https://en.wikipedia.org/wiki/Greenhouse_gas). Developing volume production using this method is the key to enabling faster carbon reduction by using hydrogen in industrial processes, [fuel cell](https://en.wikipedia.org/wiki/Fuel_cell) electric heavy truck transportation, and in gas turbine electric power generation. Methane pyrolysis is performed by having [methane](https://en.wikipedia.org/wiki/Methane) CH  
4 bubbled up through a molten metal catalyst containing dissolved [nickel](https://en.wikipedia.org/wiki/Nickel) at 1,340 K (1,070 °C; 1,950 °F). This causes the methane to break down into hydrogen gas and solid [carbon](https://en.wikipedia.org/wiki/Carbon), with no other byproducts.

CH4(g) → C(s) + 2 H2(g) ΔH° = 74 kJ/mol

The industrial quality solid carbon may be sold as manufacturing feedstock or permanently landfilled; it is not released into the atmosphere and does not cause ground water pollution in landfill. Methane pyrolysis is in development and considered suitable for commercial bulk hydrogen production. Volume production is being evaluated in the [BASF](https://en.wikipedia.org/wiki/BASF) "methane pyrolysis at scale" pilot plant. Further research continues in several laboratories, including at Karlsruhe Liquid-metal Laboratory (KALLA) and the chemical engineering laboratory at University of California – Santa Barbara

### Other industrial methods

[](https://en.wikipedia.org/wiki/File:SMR%2BWGS-1.png)

Illustrating inputs and outputs of steam reforming of natural gas, a process to produce hydrogen

Hydrogen is often produced by reacting water with [methane](https://en.wikipedia.org/wiki/Methane) and [carbon monoxide](https://en.wikipedia.org/wiki/Carbon_monoxide), which causes the removal of hydrogen from hydrocarbons at very high temperatures, with 48% of hydrogen production coming from [steam reforming](https://en.wikipedia.org/wiki/Steam_reforming). The water vapor is then reacted with the carbon monoxide produced by steam reforming to oxidize it to carbon dioxide and turn the water into hydrogen. Commercial bulk hydrogen is usually produced by the steam reforming of [natural gas](https://en.wikipedia.org/wiki/Natural_gas)[[113]](https://en.wikipedia.org/wiki/Hydrogen#cite_note-Oxtoby-115) with release of atmospheric greenhouse gas or with capture using [CCS and climate change mitigation](https://en.wikipedia.org/wiki/CCS_and_climate_change_mitigation). Steam reforming is also known as the [Bosch process](https://en.wikipedia.org/wiki/Bosch_reaction) and is widely used for the industrial preparation of hydrogen.

At high temperatures (1000–1400 K, 700–1100 °C or 1300–2000 °F), steam (water vapor) reacts with [methane](https://en.wikipedia.org/wiki/Methane) to yield carbon monoxide and H2.

CH4 + H2O → CO + 3 H2

This reaction is favored at low pressures but is nonetheless conducted at high pressures (2.0 MPa, 20 atm or 600 [inHg](https://en.wikipedia.org/wiki/InHg)). This is because high-pressure H  
2 is the most marketable product, and [pressure swing adsorption](https://en.wikipedia.org/wiki/Pressure_swing_adsorption) (PSA) purification systems work better at higher pressures. The product mixture is known as "[synthesis gas](https://en.wikipedia.org/wiki/Synthesis_gas)" because it is often used directly for the production of [methanol](https://en.wikipedia.org/wiki/Methanol) and related compounds. [Hydrocarbons](https://en.wikipedia.org/wiki/Hydrocarbon) other than methane can be used to produce synthesis gas with varying product ratios. One of the many complications to this highly optimized technology is the formation of coke or carbon:

CH4 → C + 2 H2

Consequently, steam reforming typically employs an excess of H2O. Additional hydrogen can be recovered from the steam by use of carbon monoxide through the [water gas shift reaction](https://en.wikipedia.org/wiki/Water_gas_shift_reaction), especially with an [iron oxide](https://en.wikipedia.org/wiki/Iron_oxide) catalyst. This reaction is also a common industrial source of [carbon dioxide](https://en.wikipedia.org/wiki/Carbon_dioxide):[]](https://en.wikipedia.org/wiki/Hydrogen#cite_note-Oxtoby-115)

CO + H2O → CO2 + H2

Other important methods for CO and H  
2 production include partial oxidation of hydrocarbons:

2 CH4 + O2 → 2 CO + 4 H2

and the coal reaction, which can serve as a prelude to the shift reaction above:

C + H2O → CO + H2

Hydrogen is sometimes produced and consumed in the same industrial process, without being separated. In the [Haber process](https://en.wikipedia.org/wiki/Haber_process) for the [production of ammonia](https://en.wikipedia.org/wiki/Ammonia_production), hydrogen is generated from natural gas. [Electrolysis](https://en.wikipedia.org/wiki/Electrolysis) of [brine](https://en.wikipedia.org/wiki/Brine) to yield [chlorine](https://en.wikipedia.org/wiki/Chlorine) also produces hydrogen as a co-product.

### Metal-acid

Many metals react with water to produce H  
2, but the rate of hydrogen evolution depends on the metal, the pH, and the presence alloying agents. Most commonly, hydrogen evolution is induced by acids. The alkali and alkaline earth metals, Aluminium, zinc, manganese, and iron react readily with aqueous acids. This reaction is the basis of the [Kipp's apparatus](https://en.wikipedia.org/wiki/Kipp%27s_apparatus" \o "Kipp's apparatus), which once was used as a laboratory gas source:

Zn + 2 H+→ Zn2+ + H2

In the absence of acid, the evolution of H2 is slower. Because iron is widely used structural material, its [anaerobic corrosion](https://en.wikipedia.org/wiki/Anaerobic_corrosion) is of technological significance:

Fe + 2 H2O → Fe(OH)2 + H2

Many metals, such as [aluminium](https://en.wikipedia.org/wiki/Aluminium" \o "Aluminium), are slow to react with water becausethey form passivated coatings of oxides. An alloy of aluminium and [gallium](https://en.wikipedia.org/wiki/Gallium), however, does react with water.[[117]](https://en.wikipedia.org/wiki/Hydrogen#cite_note-119) At high pH, aluminium can produce H2:

2 Al + 6 H2O + 2 OH−→ 2 Al(OH)−4 + 3 H2

Some metal-containing compounds react with acids to evolve H2. Under anaerobic conditions, [ferrous hydroxide](https://en.wikipedia.org/wiki/Ferrous_hydroxide) (Fe(OH)2) can be oxidized by the protons of water to form [magnetite](https://en.wikipedia.org/wiki/Magnetite) and H2. This process is described by the [Schikorr reaction](https://en.wikipedia.org/wiki/Schikorr_reaction" \o "Schikorr reaction):

3 Fe(OH)2 → Fe3O4 + 2 H2O + H2

This process occurs during the anaerobic corrosion of [iron](https://en.wikipedia.org/wiki/Iron) and [steel](https://en.wikipedia.org/wiki/Steel) in [oxygen-free](https://en.wikipedia.org/wiki/Anoxic_waters) [groundwater](https://en.wikipedia.org/wiki/Groundwater) and in reducing [soils](https://en.wikipedia.org/wiki/Soil) below the [water table](https://en.wikipedia.org/wiki/Water_table).

### Thermochemical

More than 200 thermochemical cycles can be used for [water splitting](https://en.wikipedia.org/wiki/Water_splitting). Many of these cycles such as the [iron oxide cycle](https://en.wikipedia.org/wiki/Iron_oxide_cycle), [cerium(IV) oxide–cerium(III) oxide cycle](https://en.wikipedia.org/wiki/Cerium(IV)_oxide%E2%80%93cerium(III)_oxide_cycle), [zinc zinc-oxide cycle](https://en.wikipedia.org/wiki/Zinc_zinc-oxide_cycle), [sulfur-iodine cycle](https://en.wikipedia.org/wiki/Sulfur-iodine_cycle), [copper-chlorine cycle](https://en.wikipedia.org/wiki/Copper-chlorine_cycle) and [hybrid sulfur cycle](https://en.wikipedia.org/wiki/Hybrid_sulfur_cycle) have been evaluated for their commercial potential to produce hydrogen and oxygen from water and heat without using electricity.[[118]](https://en.wikipedia.org/wiki/Hydrogen#cite_note-120) A number of laboratories (including in France, Germany, Greece, Japan, and the USA) are developing thermochemical methods to produce hydrogen from solar energy and water.[[119]](https://en.wikipedia.org/wiki/Hydrogen#cite_note-121)

### Serpentinization reaction

In deep geological conditions prevailing far away from the Earth's atmosphere, hydrogen (H  
2) is produced during the process of [serpentinization](https://en.wikipedia.org/wiki/Serpentinization#Hydrogen_production_by_anaerobic_oxidation_of_fayalite_ferrous_ions). In this process, water protons (H+) are reduced by ferrous (Fe2+) ions provided by [fayalite](https://en.wikipedia.org/wiki/Fayalite) (Fe2SiO4). The reaction forms [magnetite](https://en.wikipedia.org/wiki/Magnetite) (Fe3O4), [quartz](https://en.wikipedia.org/wiki/Quartz) (SiO2),and hydrogen (H2):

3Fe2SiO4 + 2 H2O → 2 Fe3O4 + 3 SiO2 + 3 H2

*faylite + water → magnetite + quartz + hydrogen*

This reaction closely resembles the [Schikorr reaction](https://en.wikipedia.org/wiki/Schikorr_reaction" \o "Schikorr reaction) observed in anaerobic oxidation of [ferrous hydroxide](https://en.wikipedia.org/wiki/Ferrous_hydroxide) in contact with water.

#### Importance of Hydrogen

Hydrogen is the first element of the periodic table. The most important function of hydrogen in the human body is to keep you hydrated. Water is made up of hydrogen and oxygen and is absorbed by the cells of the body. Therefore, it is a crucial element which is used not in our body but also as a fuel, in military weapons etc. This article deals with the importance and function of hydrogen in the human body.

The most important industrial method for the production of hydrogen is the catalytic steam– hydrocarbon process, in which gaseous or vaporized hydrocarbons are treated with steam at high pressure over a nickel catalyst at 650°–950° C to produce carbon oxides and hydrogen:

CnH2n+2 + nH2O → nCO + (2n + 1)H2; CnH2n+2 + 2nH

Hydrogen can be produced from diverse domestic resources with the potential for near-zero greenhouse gas emissions. Once produced, hydrogen generates electrical power in a fuel cell, emitting only water vapour and warm air. It holds promise for growth in both the stationary and transportation energy sectors.

**Applications**

### Petrochemical industry

Large quantities of H2 are used in the "upgrading" of fossil fuels. Key consumers of H2 include [hydrodealkylation](https://en.wikipedia.org/wiki/Hydrodealkylation), [hydrodesulfurization](https://en.wikipedia.org/wiki/Hydrodesulfurization), and [hydrocracking](https://en.wikipedia.org/wiki/Hydrocracking). Many of these reactions can be classified as [hydrogenolysis](https://en.wikipedia.org/wiki/Hydrogenolysis), i.e., the cleavage of bonds to carbon. Illustrative is the separation of sulfur from liquid fossil fuels:

R-S-R + 2 H2 → H2S + 2 RH

### Hydrogenation

[Hydrogenation](https://en.wikipedia.org/wiki/Hydrogenation), the addition of H2 to various substrates is conducted on a large scale. The hydrogenation of N2 to produce ammonia by the [Haber-Bosch process](https://en.wikipedia.org/wiki/Haber-Bosch_process) consumes a few percent of the energy budget in the entire industry. The resulting ammonia is used to supply the majority of the protein consumed by humans.[-](https://en.wikipedia.org/wiki/Hydrogen#cite_note-Smil_2004_Enriching-124) Hydrogenation is used to convert [unsaturated fats](https://en.wikipedia.org/wiki/Unsaturated_fat) and [oils](https://en.wikipedia.org/wiki/Vegetable_oil) to saturated fats and oils. The major application is the production of [margarine](https://en.wikipedia.org/wiki/Margarine). [Methanol](https://en.wikipedia.org/wiki/Methanol) is produced by hydrogenation of carbon dioxide. It is similarly the source of hydrogen in the manufacture of [hydrochloric acid](https://en.wikipedia.org/wiki/Hydrochloric_acid). H2 is also used as a [reducing agent](https://en.wikipedia.org/wiki/Reducing_agent) for the conversion of some [ores](https://en.wikipedia.org/wiki/Ore) to the metals.

### Coolant

[*Hydrogen-cooled turbo generator*](https://en.wikipedia.org/wiki/Hydrogen-cooled_turbo_generator)

Hydrogen is commonly used in power stations as a coolant in generators due to a number of favorable properties that are a direct result of its light diatomic molecules. These include low [density](https://en.wikipedia.org/wiki/Density), low [viscosity](https://en.wikipedia.org/wiki/Viscosity), and the highest [specific heat](https://en.wikipedia.org/wiki/Specific_heat_capacity) and [thermal conductivity](https://en.wikipedia.org/wiki/Thermal_conductivity) of all gases.

### Energy carrier

Hydrogen is not an energy resource as a combustion fuel because there is no naturally occurring source of hydrogen in useful quantities. The Sun's energy comes from [nuclear fusion](https://en.wikipedia.org/wiki/Stellar_nucleosynthesis) of hydrogen, but this process is difficult to achieve controllably on Earth. Elemental hydrogen from solar, biological, or electrical sources requires more energy to make than is obtained by burning it, so in these cases hydrogen functions as an energy carrier, like a battery. Hydrogen may be obtained from fossil sources (such as methane), but these sources are unsustainable.

The [energy density](https://en.wikipedia.org/wiki/Energy_density) per unit *volume* of both [liquid hydrogen](https://en.wikipedia.org/wiki/Liquid_hydrogen) and [compressed hydrogen](https://en.wikipedia.org/wiki/Compressed_hydrogen) gas at any practicable pressure is significantly less than that of traditional fuel sources, although the energy density per unit fuel *mass* is higher. Nevertheless, elemental hydrogen has been widely discussed in the context of energy, as a possible future *carrier* of energy on an economy-wide scale. For example, CO  
2 [sequestration](https://en.wikipedia.org/wiki/CO2_sequestration) followed by [carbon capture and storage](https://en.wikipedia.org/wiki/Carbon_capture_and_storage) could be conducted at the point of H  
2 production from fossil fuels. Hydrogen used in transportation would burn relatively cleanly, with some [NOx](https://en.wikipedia.org/wiki/NOx) emissions, but without carbon emissions. However, the infrastructure costs associated with full conversion to a hydrogen economy would be substantial. [Fuel cells](https://en.wikipedia.org/wiki/Fuel_cell) can convert hydrogen and oxygen directly to electricity more efficiently than internal combustion engines.

### Semiconductor industry

Hydrogen is employed to saturate broken ("dangling") bonds of [amorphous silicon](https://en.wikipedia.org/wiki/Amorphous_silicon) and [amorphous carbon](https://en.wikipedia.org/wiki/Amorphous_carbon) that helps stabilizing material properties. It is also a potential [electron donor](https://en.wikipedia.org/wiki/Electron_donor) in various oxide materials, including [ZnO](https://en.wikipedia.org/wiki/Zinc_oxide),[SnO2](https://en.wikipedia.org/wiki/Tin_dioxide), [CdO](https://en.wikipedia.org/wiki/Cadmium_oxide), [MgO](https://en.wikipedia.org/wiki/Magnesium_oxide), [ZrO2](https://en.wikipedia.org/wiki/Zirconium_dioxide), [HfO2](https://en.wikipedia.org/wiki/Hafnium(IV)_oxide), [La2O3](https://en.wikipedia.org/wiki/Lanthanum(III)_oxide), [Y2O3](https://en.wikipedia.org/wiki/Yttrium(III)_oxide), [TiO2](https://en.wikipedia.org/wiki/Titanium_dioxide), [SrTiO3](https://en.wikipedia.org/wiki/Strontium_titanate), [LaAlO3](https://en.wikipedia.org/wiki/Lanthanum_aluminate), [SiO2](https://en.wikipedia.org/wiki/Silicon_dioxide), [Al2O3](https://en.wikipedia.org/wiki/Aluminium_oxide), [ZrSiO4](https://en.wikipedia.org/wiki/Zircon), [HfSiO4](https://en.wikipedia.org/wiki/Hafnon), and [SrZrO3](https://en.wikipedia.org/w/index.php?title=Strontium_zirconate&action=edit&redlink=1).

### Rocket propellant

[Liquid hydrogen](https://en.wikipedia.org/wiki/Liquid_hydrogen) and [liquid oxygen](https://en.wikipedia.org/wiki/Liquid_oxygen) together serve as [cryogenic fuel](https://en.wikipedia.org/wiki/Cryogenic_fuel) in [liquid-propellant rockets](https://en.wikipedia.org/wiki/Liquid-propellant_rocket), as in the [Space Shuttle main engines](https://en.wikipedia.org/wiki/RS-25).

### Niche and evolving uses

* **Shielding gas:** Hydrogen is used as a [shielding gas](https://en.wikipedia.org/wiki/Shielding_gas) in [welding](https://en.wikipedia.org/wiki/Welding) methods such as [atomic hydrogen welding](https://en.wikipedia.org/wiki/Atomic_hydrogen_welding).
* **Cryogenic research:** Liquid H2 is used in [cryogenic](https://en.wikipedia.org/wiki/Cryogenic) research, including [superconductivity](https://en.wikipedia.org/wiki/Superconductivity) studies.
* **Buoyant lifting:** Because H2 is lighter than air, having only 7% of the density of air, it was once widely used as a [lifting gas](https://en.wikipedia.org/wiki/Lifting_gas) in balloons and [airships](https://en.wikipedia.org/wiki/Airship).
* **Leak detection:** Pure or mixed with nitrogen (sometimes called [forming gas](https://en.wikipedia.org/wiki/Forming_gas)), hydrogen is a [tracer gas](https://en.wikipedia.org/wiki/Tracer_gas) for [detection](https://en.wikipedia.org/wiki/Leak_detection) of minute leaks. Applications can be found in the automotive, chemical, power generation, aerospace, and telecommunications industries.[[140]](https://en.wikipedia.org/wiki/Hydrogen#cite_note-142) Hydrogen is an authorized food additive (E 949) that allows food package leak testing, as well as having anti-oxidizing properties.
* **Neutron moderation:** [Deuterium](https://en.wikipedia.org/wiki/Deuterium) (hydrogen-2) is used in [nuclear fission applications](https://en.wikipedia.org/wiki/CANDU_reactor) as a [moderator](https://en.wikipedia.org/wiki/Neutron_moderator) to slow [neutrons](https://en.wikipedia.org/wiki/Neutron).
* **Nuclear fusion fuel:** Deuterium is used in [nuclear fusion](https://en.wikipedia.org/wiki/Nuclear_fusion) reactions.[[6]](https://en.wikipedia.org/wiki/Hydrogen#cite_note-nbb-6)
* **Isotopic labeling:** Deuterium compounds have applications in chemistry and biology in studies of [isotope effects](https://en.wikipedia.org/wiki/Kinetic_isotope_effect) on reaction rates.[[142]](https://en.wikipedia.org/wiki/Hydrogen#cite_note-144)
* **Rocket propellant:** [NASA](https://en.wikipedia.org/wiki/NASA) has investigated the use of [rocket propellant](https://en.wikipedia.org/wiki/Rocket_propellant) made from atomic hydrogen, boron or carbon that is frozen into solid molecular hydrogen particles that are suspended in liquid helium. Upon warming, the mixture vaporizes to allow the atomic species to recombine, heating the mixture to high temperature.
* **Tritium uses:** [Tritium](https://en.wikipedia.org/wiki/Tritium) (hydrogen-3), produced in [nuclear reactors](https://en.wikipedia.org/wiki/Nuclear_reactor), is used in the production of [hydrogen bombs](https://en.wikipedia.org/wiki/Hydrogen_bomb), as an isotopic label in the biosciences, and as a source of [beta radiation](https://en.wikipedia.org/wiki/Beta_particle) in [radioluminescent paint](https://en.wikipedia.org/wiki/Tritium_radioluminescence" \o "Tritium radioluminescence) for instrument dials and emergency signage.

Hydrogen is quickly becoming a global contender for alternative energy, but these applications actually account for less than 10% of global hydrogen consumption. As the hydrogen economy grows, the world is rethinking the way that hydrogen is produced, transferred, and utilized

Hydrogen also has a long history of use in several other industries. These include:

##### Food:

Hydrogen is used to turn unsaturated fats into to saturated oils and fats, including hydrogenated vegetable oils like margarine and butter spreads.

##### Metalworking:

Hydrogen is used in multiple applications including metal alloying and iron flashmaking.

##### Welding:

Atomic hydrogen welding (AHW) is a type of arc welding which utilizes a hydrogen environment.

##### Flat Glass Production:

A mixture of hydrogen and nitrogen is used to prevent oxidation and therefore defects during manufacturing.

##### Electronics Manufacturing:

As an efficient reducing and etching agent, hydrogen is used to create semiconductors, LEDs, displays, photovoltaic segments, and other electronics.

##### Medical:

Hydrogen is used to create hydrogen peroxide (H2O2). Recently, hydrogen gas has also been studied as [a therapeutic gas for a number of different diseases](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5731988/).

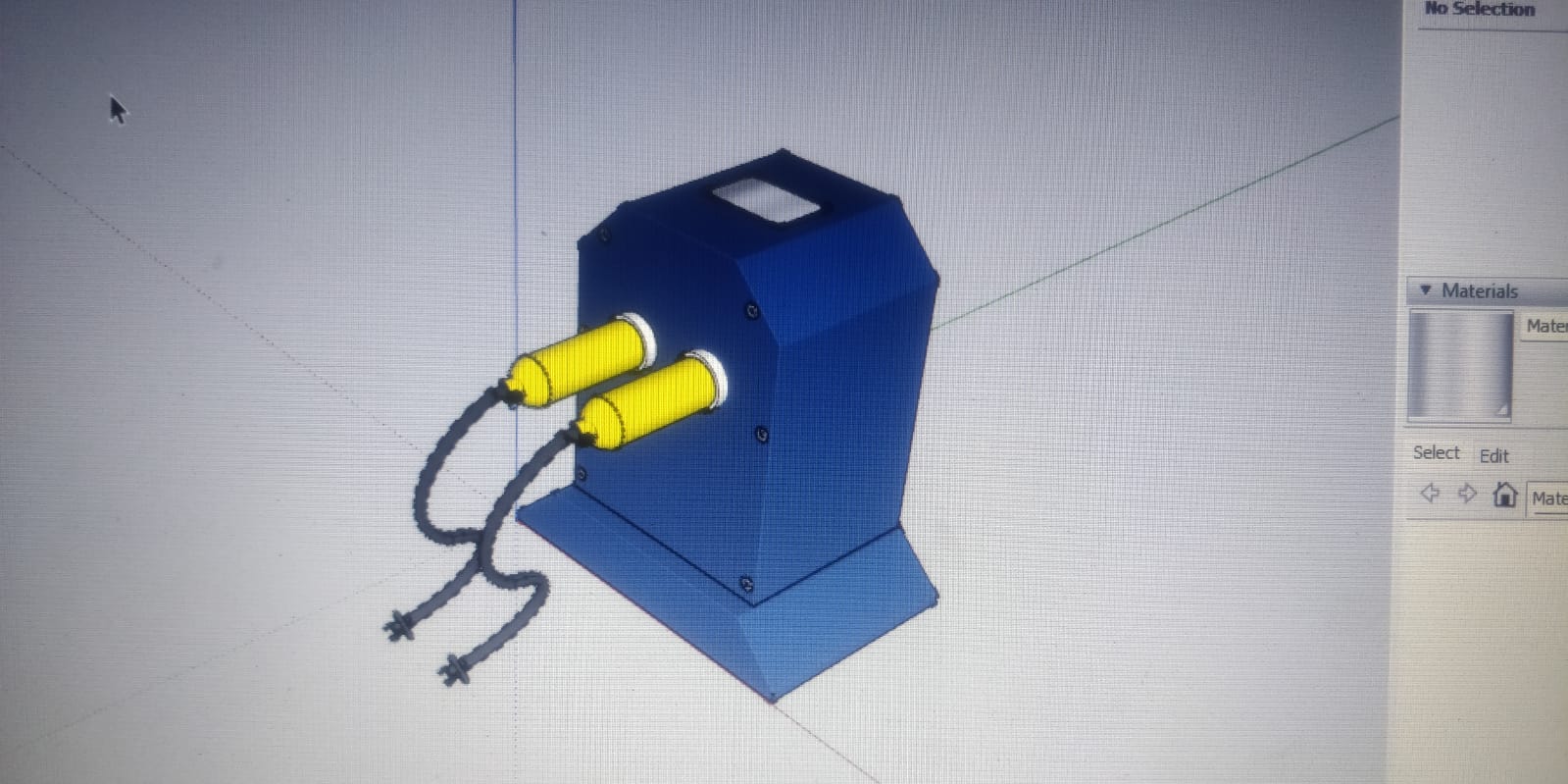
## HHO Gas : Sustainable treatment for COVID-19 and other respiratory diseases

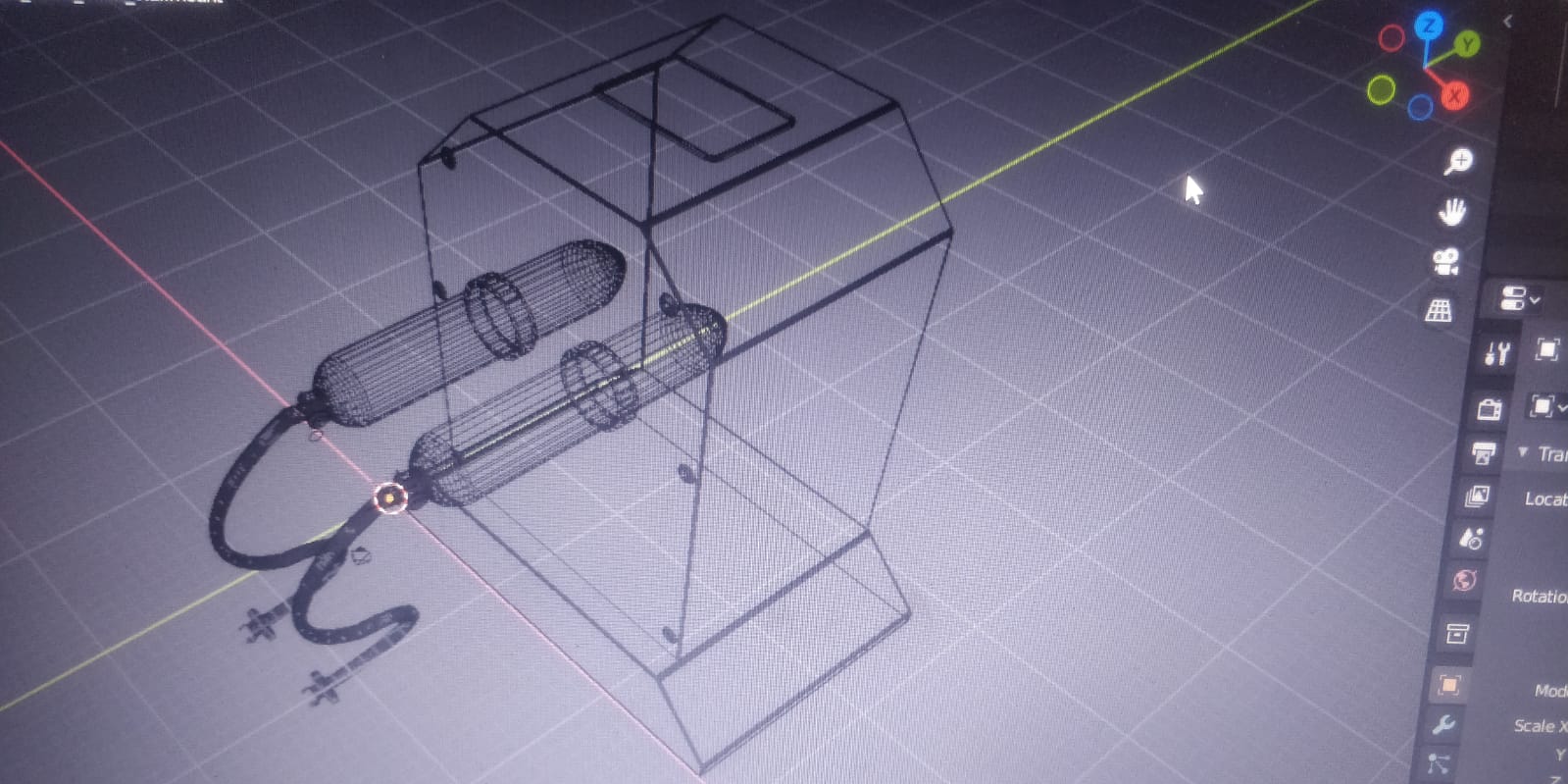
Oxy-hydrogen gas (HHO) is a gaseous mixture of molecular hydrogen and molecular oxygen that is generated by the electrolysis of water and delivered in a 2:1 ratio (66% and 33%, respectively) through the use of noninvasive inhalation devices such as nasal cannulas or nebulisers. Although there is a paucity of scientific evidence supporting this new and emerging therapy, initial investigations indicate that HHO proffers cytoprotective qualities, typically by reducing oxidative stress and attenuating the inflammatory response. These aspects are particularly favourable when considering respiratory medicine because underlying inflammation is known to drive the pathological progress of numerous respiratory conditions, including asthma, chronic obstructive pulmonary disorder, and, pertinently, coronavirus disease (COVID-19). Direct delivery to the lung parenchyma is also likely to increase the effectiveness of this emerging medical therapy.

This narrative review aims to delineate how this particular combination of gases can affect cellular processes at the molecular level by focussing on the evolutionary requirement for both oxygen and hydrogen. Furthermore, the authors assess the current available data for the safety and efficacy of HHO in a clinical setting.

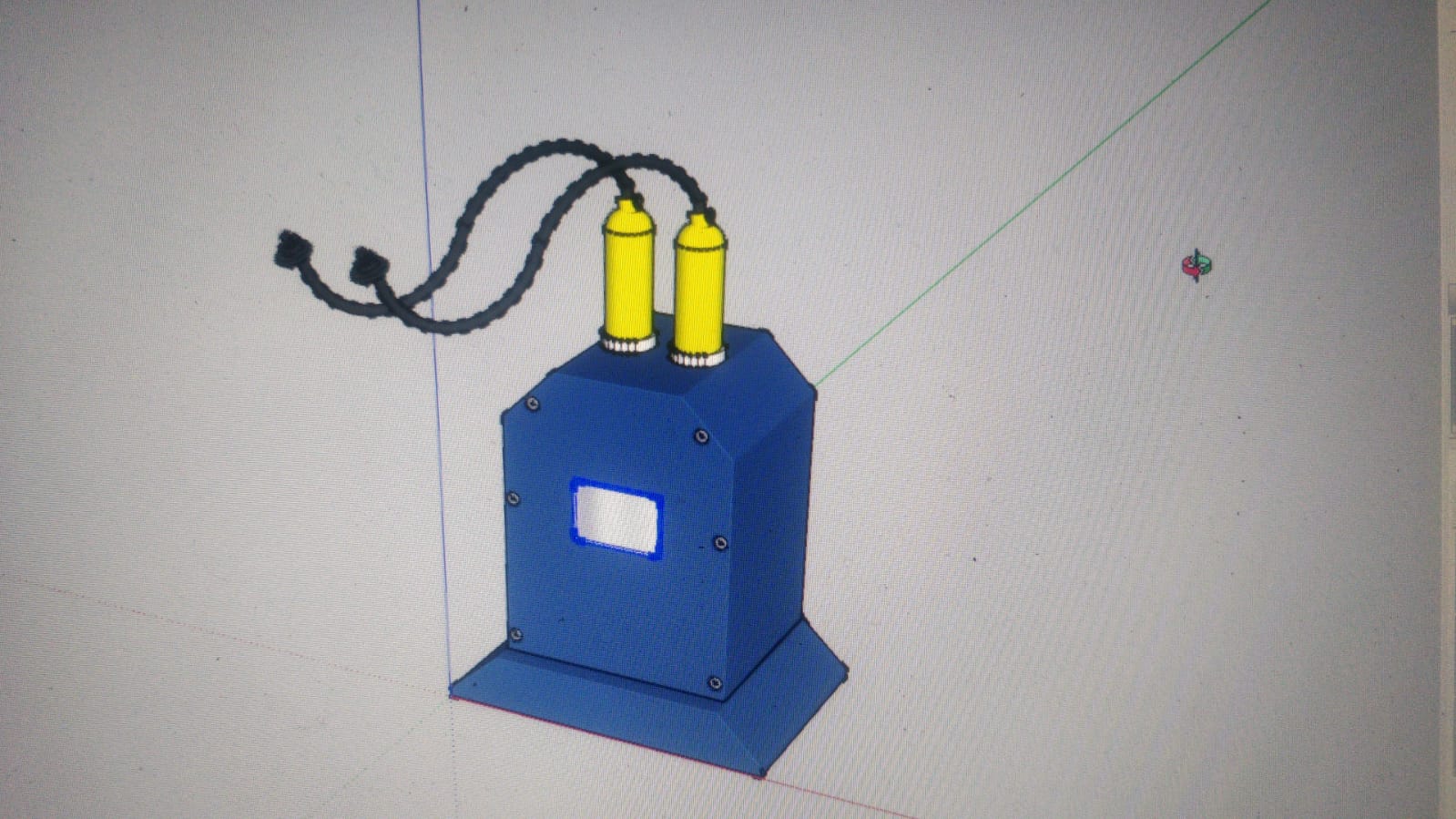
# Design Of Oxygen Hydrogen Generator And Cost Effect

# C:\Users\HP\Downloads\WhatsApp Image 2022-04-28 at 3.23.41 PM.jpeg





Final Design of our project



1. Conclusion

In this study, we discussed the potential demand of by-product oxygen and its contribution to energy saving. Because there are the large quantities of potential oxygen demand, the by-product oxygen of electrolysis hydrogen production could be fully utilized, which would contribute to the improvement of various energy efficiency of industrial processes and electric power production, the reduction of CO2 emission. Even if the large quantities of by-product oxygen are wasted, the use of by-product oxygen in hospital would be economic merit ,As compared to the product available in the market we have made it cost effective.