

INDUSTRIAL PROCESS

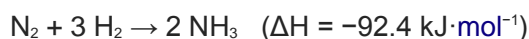
INDUSTRIAL PROCESS

SESSION 2 CHEMICAL PROCESS

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The **Haber process**, also called the **Haber–Bosch process**, is the industrial implementation of the reaction of [nitrogen gas](#) and [hydrogen gas](#). It is the main industrial procedure to produce [ammonia](#).^[1]



Nitrogen is a strong limiting nutrient in plant growth. Carbon and oxygen are also critical, but are easily obtained by plants from soil and air. Even though [air](#) is 78% [nitrogen](#), atmospheric nitrogen is nutritionally unavailable because nitrogen molecules are held together by strong [triple bonds](#). Nitrogen must be 'fixed', i.e. converted into some bioavailable form, through natural or man-made processes. It was not until the early 20th century that [Fritz Haber](#) developed the first practical process to convert atmospheric nitrogen to ammonia, which is nutritionally available. Prior to the discovery of the Haber process, ammonia had been difficult to produce on an industrial scale.^{[2][3][4][5]} Nitrogen fixation was already being done on an industrial scale using the [Birkeland–Eyde process](#), but this is very energy-inefficient.

Fertilizer generated from ammonia produced by the Haber process is estimated to be responsible for sustaining one-third of the Earth's population.^[6] It is estimated that half of the protein within human beings is made of nitrogen that was originally fixed by this process; the remainder was produced by [nitrogen fixing bacteria and archaea](#).^[7]

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History

Main article: [History of the Haber process](#)

Early in the twentieth century, several chemists tried to make ammonia from atmospheric nitrogen. German chemist [Fritz Haber](#) discovered a process that is still used today.^[8]

[Robert Le Rossignol](#) was instrumental in the development of the high-pressure devices used in the Haber process.^[9] They demonstrated their process in the summer of 1909 by producing ammonia from air drop by drop, at the rate of about 125 ml (4 US fl oz) per hour. The process was purchased by the German chemical company [BASF](#), which assigned [Carl Bosch](#) the task of scaling up Haber's tabletop machine to industrial-level production.^{[3][10]} He succeeded in this process in 1910. Haber and Bosch were later awarded [Nobel prizes](#), in 1918 and 1931

respectively, for their work in overcoming the chemical and engineering problems posed by the use of large-scale, continuous-flow, high-pressure technology.

Ammonia was first manufactured using the Haber process on an industrial scale in 1913 in BASF's [Oppau](#) plant in Germany, production reaching 20 tonnes/day the following year.^[11] During World War I, the synthetic ammonia was used for the production of [nitric acid](#), a precursor to munitions. The Allies had access to large amounts of [sodium nitrate](#) deposits in Chile (so called "Chile saltpetre") that belonged almost totally to British industries. As Germany lacked access to such readily available natural resources, the Haber process proved important to the German war effort.^[12]

The process



A historical (1921) high-pressure steel reactor for production of ammonia via the Haber process is displayed at the [Karlsruhe Institute of Technology](#), Germany.

This conversion is typically conducted at 15–25 [MPa](#) (2,200–3,600 [psi](#)) or 150–250 [bar](#) and between 300–550 °C (572–1,022 °F), as the gases are passed over four beds of [catalyst](#), with cooling between each pass so as to maintain a reasonable [equilibrium constant](#). On each pass only about 15% conversion occurs, but any unreacted gases are recycled, and eventually an overall conversion of 97% is achieved.^[1]

The steam reforming, shift conversion, carbon dioxide removal, and methanation steps each operate at absolute pressures of about 2.5–3.5 MPa (360–510 psi) or 25–35 bar, and the ammonia synthesis loop operates at absolute pressures ranging from ^[clarification needed] 6–18 MPa (870–2,610 psi) or 60–180 bar, depending upon which proprietary process design is used.^[1]

Sources of hydrogen[

The major source is [methane](#) from [natural gas](#). The conversion, [steam reforming](#), is conducted with air, which is deoxygenated by the combustion of natural gas. Originally Bosch obtained [hydrogen](#) by the [electrolysis of water](#).

Reaction rate and equilibrium[\[edit\]](#)

Nitrogen (N₂) is very unreactive because the [molecules](#) are held together by strong [triple bonds](#). The Haber process relies on catalysts that accelerate the scission of this triple bond.

Two opposing considerations are relevant to this synthesis: the position of the equilibrium and the [rate of reaction](#). At room temperature, the equilibrium is strongly in favor of ammonia, but the reaction doesn't proceed at a detectable rate. The obvious solution is to raise the temperature, but because the reaction is [exothermic](#), the equilibrium constant (using [atm](#) units) becomes 1 around 150° or 200 °C. (See [Le Chatelier's principle](#).)

K_p(T) for N₂ + 3 H₂ ⇌ 2 NH₃ <small>[13]</small>	
Temperature (°C)	K _p
300	4.34 x 10 ⁻³
400	1.64 x 10 ⁻⁴
450	4.51 x 10 ⁻⁵
500	1.45 x 10 ⁻⁵
550	5.38 x 10 ⁻⁶
600	2.25 x 10 ⁻⁶

Above this temperature, the equilibrium quickly becomes quite unfavourable at atmospheric pressure, according to the [Van 't Hoff equation](#). Thus one might suppose that a low temperature is to be used and some other means to increase rate. However, the catalyst itself requires a temperature of at least 400 °C to be efficient.

[Pressure](#) is the obvious choice to favour the forward reaction because there are 4 moles of reactant for every 2 moles of product (see [entropy](#)), and the pressure used (around 200 atm) alters the equilibrium concentrations to give a profitable yield. ^{[[citation needed](#)]}

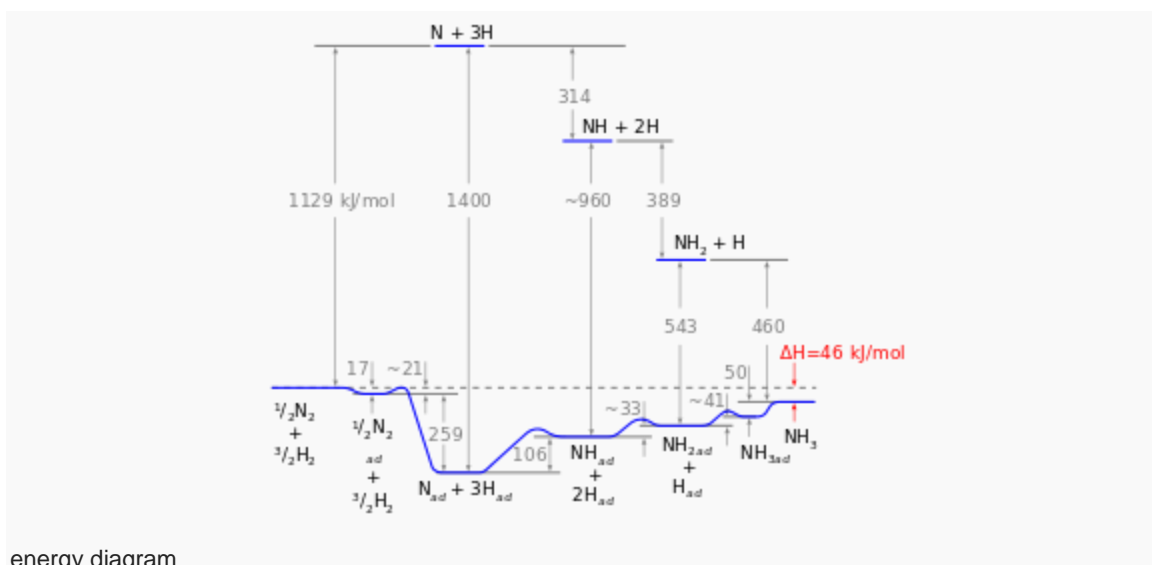
Economically, though, pressure is an expensive commodity. Pipes and reaction vessels need to be strengthened, valves more rigorous, and there are safety considerations of working at 200 atm. In addition, running pumps and compressors takes considerable energy. Thus the compromise used gives a single pass yield of around 15%. ^{[[citation needed](#)]}

Another way to increase the yield of the reaction would be to remove the product (i.e. ammonia gas) from the system. In practice, gaseous ammonia is not removed from the reactor itself, since the temperature is too high; but it is removed from the equilibrium mixture of gases leaving the reaction vessel. The hot gases are cooled enough, whilst maintaining a high pressure, for the ammonia to condense and be removed as liquid. Unreacted hydrogen and nitrogen gases are then returned to the reaction vessel to undergo further reaction. ^{[[citation needed](#)]}

Catalysts^{[[edit](#)]}

The most popular catalysts are based on iron promoted with K_2O , CaO , SiO_2 , and Al_2O_3 . The original Haber–Bosch reaction chambers used [osmium](#) as the catalyst (however [uranium](#) was noted to be superior but harder to obtain by Haber). However, under Bosch's direction in 1909, the BASF researcher [Alwin Mittasch](#) discovered a much less expensive [iron](#)-based catalyst, which is still used today. Some ammonia production utilizes [ruthenium](#)-based catalysts (the KAAP process). Ruthenium forms more active catalysts that allows milder operating pressures. Such catalysts are prepared by decomposition of [triruthenium dodecacarbonyl](#) on [graphite](#).^[1]

In industrial practice, the iron catalyst is obtained from finely ground iron powder, which in turn is usually obtained by reduction of high purity [magnetite](#) (Fe_3O_4). The pulverized iron metal is burnt (oxidized) to give magnetite of a defined particle size. The magnetite particles are then partially reduced, removing some of the [oxygen](#) in the process. The resulting catalyst particles consist of a core of magnetite, encased in a shell of [wüstite](#) (FeO), which in turn is surrounded by an outer shell of iron metal. The catalyst maintains most of its bulk volume during the reduction, resulting in a highly porous high surface area material, which enhances its effectiveness as a catalyst. Other minor components of the catalyst include [calcium](#) and [aluminium oxides](#), which support the iron catalyst and help it maintain its surface area. These oxides of Ca, Al, K, and Si are immune to reduction by the hydrogen.^[1]



The [reaction mechanism](#), involving the heterogeneous catalyst, is believed to involve the following steps:^{[[citation needed](#)]}

1. $\text{N}_2(\text{g}) \rightarrow \text{N}_2(\text{adsorbed})$
2. $\text{N}_2(\text{adsorbed}) \rightarrow 2 \text{N}(\text{adsorbed})$
3. $\text{H}_2(\text{g}) \rightarrow \text{H}_2(\text{adsorbed})$
4. $\text{H}_2(\text{adsorbed}) \rightarrow 2 \text{H}(\text{adsorbed})$
5. $\text{N}(\text{adsorbed}) + 3 \text{H}(\text{adsorbed}) \rightarrow \text{NH}_3(\text{adsorbed})$
6. $\text{NH}_3(\text{adsorbed}) \rightarrow \text{NH}_3(\text{g})$

Reaction 5 occurs in three steps, forming NH, NH₂, and then NH₃. Experimental evidence points to reaction 2 as being the slow, [rate-determining step](#). This is not unexpected since the bond broken, the nitrogen triple bond, is the strongest of the bonds that must be broken.

A major contributor to the elucidation of this mechanism is [Gerhard Ertl](#).^[14]

Economic and environmental aspects^{[[edit](#)]}

Further information: [Sustainable ammonia production](#)

The Haber process now produces 500 million short tons (454 million tonnes) of nitrogen [fertilizer](#) per year, mostly in the form of anhydrous [ammonia](#), [ammonium nitrate](#), and [urea](#). 3–5% of the world's natural gas production is consumed in the Haber process (~1–2% of the world's annual energy supply).^{[15][16][17][18]} In combination with pesticides, these fertilizers have quadrupled the productivity of agricultural land:

With average crop yields remaining at the 1900 level the crop harvest in the year 2000 would have required nearly four times more land and the cultivated area would have claimed nearly

half of all ice-free continents, rather than under 15% of the total land area that is required today.^[19]

Due to its dramatic impact on the human ability to grow food, the Haber process served as the "detonator of the population explosion", enabling the global population to increase from 1.6 billion in 1900 to today's 7 billion.^[20] According to Howarth (2008), nearly 80% of the nitrogen found in human tissues originated from the Haber-Bosch process.^[21] Since nitrogen use efficiency is typically less than 50%,^[22] our heavy use of industrial nitrogen fixation is severely disruptive to our biological habitat.^[21]

Smelting is a form of [extractive metallurgy](#); its main use is to produce a [metal](#) from its [ore](#). This includes production of [silver](#), [iron](#), [copper](#) and other [base metals](#) from their ores. Smelting uses heat and a chemical [reducing agent](#) to decompose the ore, driving off other elements as gasses or slag and leaving just the metal behind. The reducing agent is commonly a source of [carbon](#) such as [coke](#), or in earlier times [charcoal](#). The carbon (or [carbon monoxide](#) derived from it) removes [oxygen](#) from the ore, leaving behind elemental metal. The carbon is thus oxidized in two stages, producing first carbon monoxide and then [carbon dioxide](#). As most ores are impure, it is often necessary to use [flux](#), such as [limestone](#), to remove the accompanying rock [gangue](#) as [slag](#). Plants for the [electrolytic](#) reduction of [aluminium](#) are also generally referred to as [aluminium smelters](#).

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Process

Smelting involves more than just melting the metal out of its ore. Most ores are a chemical compound of the metal with other elements, such as oxygen (as an [oxide](#)), sulfur (as a [sulfide](#)) or carbon and oxygen together (as a [carbonate](#)). To produce the metal, these compounds have to

undergo a chemical reaction. Smelting therefore consists of using suitable [reducing substances](#) that will combine with those [oxidizing](#) elements to free the metal.

Roasting

In the case of carbonates and sulfides, a process called "roasting" drives out the unwanted carbon or sulfur, leaving an oxide, which can be directly reduced. Roasting is usually carried out in an oxidizing environment. A few practical examples:

- [Malachite](#), a common ore of [copper](#), is primarily copper carbonate (CuCO_3). This mineral undergoes thermal decomposition to CuO and CO_2 in several stages between 250°C and 350°C . The carbon dioxide is expelled into the atmosphere, leaving copper oxide which can be directly reduced to copper as described in the following section titled Reduction.
- [Galena](#), the most common mineral of [lead](#), is primarily lead sulfide (PbS). The sulfide is oxidized to a sulfite (PbSO_3) which thermally decomposes into lead oxide and sulfur dioxide gas. (PbO and SO_2) The [sulfur dioxide](#) is expelled (like the [carbon dioxide](#) in the previous example), and the lead oxide is reduced as below.

Reduction

Reduction is the final, high-temperature step in smelting. It is here that the oxide becomes the elemental metal. A reducing environment (often provided by carbon monoxide, made by incomplete combustion, produced in an air-starved furnace) pulls the final oxygen atoms from the raw metal. The required temperature varies over a very large range, both in absolute terms and in terms of the melting point of the base metal. A few examples:


- iron oxide becomes metallic iron at roughly 1250°C , almost 300 degrees *below* iron's melting point of 1538°C
- mercuric oxide becomes vaporous mercury near 550°C , almost 600 degrees *above* mercury's melting point of -38°C

Flux and slag can provide a secondary service after the reduction step is complete: They provide a molten cover on the purified metal, preventing it from coming into contact with oxygen while it is still hot enough to oxidize readily.

Fluxes

Fluxes are used in smelting for several purposes, chief among them catalyzing the desired reactions and chemically binding to unwanted impurities or reaction products. Calcium oxide, in the form of lime, was often used for this purpose, since it could react with the carbon dioxide and sulfur dioxide produced during roasting and smelting to keep them out of the working environment.

History



Of the [seven metals known in antiquity](#) only [gold](#) occurred regularly in native form in the natural environment. The others – [copper](#), [lead](#), [silver](#), [tin](#), [iron](#) and [mercury](#) – occur primarily as minerals, though copper is occasionally found in its [native state](#) in commercially significant quantities. These minerals are primarily carbonates, sulfides, or oxides of the metal, mixed with other components such as silica and alumina. [Roasting](#) the carbonate and sulfide minerals in air converts them to oxides. The oxides, in turn, are smelted into the metal. Carbon monoxide was (and is) the reducing agent of choice for smelting. It is easily produced during the heating process, and as a gas comes into intimate contact with the ore.

In the [Old World](#), humans learned to smelt metals in [prehistoric](#) times, more than 8000 years ago. The discovery and use of the "useful" metals — copper and bronze at first, then iron a few millennia later — had an enormous impact on human society. The impact was so pervasive that scholars traditionally divide ancient history into [Stone Age](#), [Bronze Age](#), and [Iron Age](#).

In the [Americas](#), pre-[Inca](#) civilizations of the central [Andes](#) in Peru had mastered the smelting of copper and silver at least six centuries before the first Europeans arrived in the 16th century.^[1]

Tin and lead

In the [Old World](#), the first metals smelted were tin and lead. The earliest known cast lead beads were found in the [Çatal Höyük](#) site in [Anatolia \(Turkey\)](#), and dated from about 6500 BC, but the metal may have been known earlier.

Since the discovery happened several millennia before the invention of writing, there is no written record about how it was made. However, tin and lead can be smelted by placing the ores in a wood fire, leaving the possibility that the discovery may have occurred by accident.

Although lead is a common metal, its discovery had relatively little impact in the ancient world. It is too soft to be used for structural elements or weapons, excepting for the fact that it is exceptionally heavy, making it ideal for [sling](#) projectiles. However, being easy to cast and shape, it came to be extensively used in the classical world of [Ancient Greece](#) and [Ancient Rome](#) for piping and storage of water. It was also used as a [mortar](#) in stone buildings.

Tin was much less common than lead and is only marginally harder, and had even less impact by itself.

Copper and bronze

After tin and lead, the next metal to be smelted appears to have been copper. How the discovery came about is a matter of much debate. Campfires are about 200 °C short of the temperature needed for that, so it has been conjectured that the first smelting of copper may have been achieved

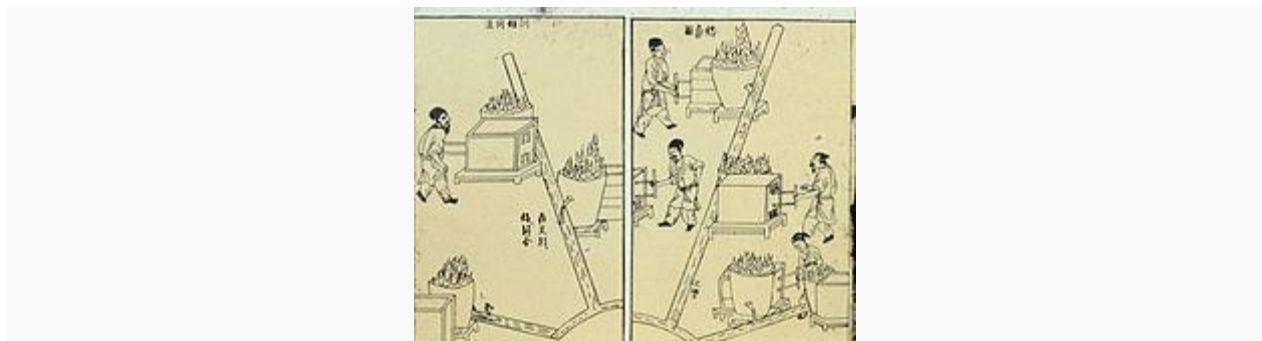
in pottery [kilns](#). The development of copper smelting in the Andes, which is believed to have occurred independently of that in the [Old World](#), may have occurred in the same way.^[1] The earliest current evidence of copper smelting, dating from between 5500 BC and 5000 BC, has been found in [Pločnik](#) and [Belovode](#), Serbia.^{[2][3]} A mace head found in [Can Hasan](#), Turkey and dated to 5000 BC, once thought to be the oldest evidence, now appears to be hammered native copper.^[4]

By combining copper with tin and/or [arsenic](#) in the right proportions one obtains [bronze](#), an [alloy](#) which is significantly harder than copper. The first [copper/arsenic bronzes](#) date from [4200 BC](#) from [Asia Minor](#). The Inca bronze alloys were also of this type. Arsenic is often an impurity in copper ores, so the discovery could have been made by accident; but eventually arsenic-bearing minerals were intentionally added during smelting.^[citation needed]

Copper–tin bronzes, harder and more durable, were developed around 3200 BC, also in Asia Minor.^[citation needed]

The process through which the smiths learned to produce copper/tin bronzes is once again a mystery. The first such bronzes were probably a lucky accident from tin contamination of copper ores, but by 2000 BC, we know that tin was being mined on purpose for the production of bronze. This is amazing, given that tin is a semi-rare metal, and even a rich [cassiterite](#) ore only has 5% tin. Also, it takes special skills (or special instruments) to find it and to locate the richer lodes. But, whatever steps were taken to learn about tin, these were fully understood by 2000 BC.

The discovery of copper and bronze manufacture had a significant impact on the history of the [Old World](#). Metals were hard enough to make weapons that were heavier, stronger, and more resistant to impact-related damage than their wood, bone, or stone equivalents. For several millennia, bronze was the material of choice for weapons such as [swords](#), [daggers](#), [battle axes](#), and [spear](#) and [arrow](#) points, as well as protective gear such as [shields](#), [helmets](#), [greaves](#) (metal shin guards), and other [body armor](#). Bronze also supplanted stone, wood, and organic materials in all sorts of tools and household utensils, such as [chisels](#), [saws](#), [adzes](#), [nails](#), [blade shears](#), [knives](#), [sewing needles](#) and [pins](#), [jugs](#), [cooking pots](#) and [cauldrons](#), [mirrors](#), [horse harnesses](#), and much more.^[citation needed] Tin and copper also contributed to the establishment of trade networks spanning large areas of Europe and Asia, and had a major effect on the distribution of wealth among individuals and nations.^[citation needed]



Casting bronze ding-tripods, from the Chinese *Tiangong Kaiwu* encyclopedia of [Song Yingxing](#), published in 1637.

Early iron smelting

Main article: [Ferrous metallurgy](#)

Where and how iron smelting was discovered is widely debated, and remains uncertain due to the significant lack of production finds. Nevertheless, there is some consensus^{[\[citation needed\]](#)} that iron technology originated in the Near East, perhaps in Eastern Anatolia.

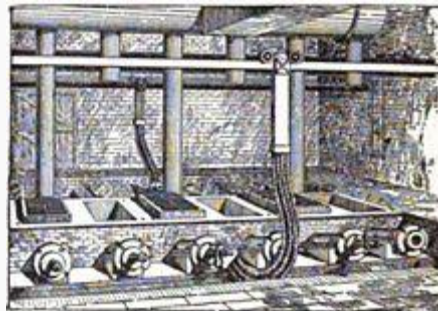
In [Ancient Egypt](#), somewhere between the [Third Intermediate Period](#) and [23rd Dynasty](#) (ca. 1100–750 BC), there are indications of iron working. Significantly though, no evidence for the smelting of iron from ore has been attested to Egypt in any (pre-modern) period. There is a further possibility of iron smelting and working in [West Africa](#) by 1200 BC.^{[\[6\]](#)} In addition, very early instances of [carbon steel](#) were found to be in production around 2000 years before the present in northwest [Tanzania](#), based on complex preheating principles. These discoveries are significant for the history of metallurgy.^{[\[6\]](#)}

Most early processes in Europe and Africa involved smelting iron ore in a [bloomery](#), where the temperature is kept low enough so that the iron does not melt. This produces a spongy mass of iron called a bloom, which then has to be consolidated with a hammer. The earliest evidence to date for the bloomery smelting of iron is found at [Tell Hammeh](#), Jordan ([see also external link](#)), and dates to 930 BC ([C14 dating](#)).

Later iron smelting

From the medieval period, the process of direct reduction in bloomeries began to be replaced by an indirect process. In this, a [blast furnace](#) was used to make [pig iron](#), which then had to undergo a further process to make forgeable bar iron. Processes for the second stage include fining in a [finery forge](#) and, from the [Industrial Revolution](#), [puddling](#). However both processes are now obsolete, and wrought iron is now hardly made. Instead, mild steel is produced from a [bessemer converter](#) or by other means including smelting reduction processes such as the [Corex Process](#).

Base metals



[Cowles Syndicate](#) of [Ohio](#) in [Stoke-upon-Trent England](#), late 1880s. [British Aluminium](#) used the process of [Paul Héroult](#) about this time.^[7]

The ores of base metals are often sulfides. In recent centuries, [reverberatory furnaces](#) have been used. These keep the fuel and the charge being smelted separate. Traditionally these were used for carrying out the first step: formation of two liquids, one an oxide slag containing most of the impurity elements, and the other a sulfide [matte](#) containing the valuable metal sulfide and some impurities. Such "reverb"[furnaces](#) are today about 40 m long, 3 m high and 10 m wide. Fuel is burned at one end and the heat melts the dry sulfide concentrates (usually after partial roasting), which are fed through the openings in the roof of the furnace. The slag floats on top of the heavier matte, and is removed and discarded or recycled. The sulfide matte is then sent to the [converter](#). The precise details of the process will vary from one furnace to another depending on the mineralogy of the orebody from which the concentrate originates.

While reverberatory furnaces were very good at producing slags containing very little copper, they were relatively energy inefficient and produced a low concentration of [sulfur dioxide](#) in their off-gases that made it difficult to capture, and consequently, they have been supplanted by a new generation of copper smelting technologies.^[8] More recent furnaces have been designed based upon bath smelting, top jetting lance smelting, [flash smelting](#) and blast furnaces. Some examples of bath smelters include the Noranda furnace, the [Isasmelt](#) furnace, the Teniente reactor, the Vunyuikov smelter and the SKS technology to name a few. Top jetting lance smelters include the Mitsubishi smelting reactor. Flash smelters account for over 50% of the world's copper smelters. There are many more varieties of smelting processes, including the Kivset, Ausmelt, Tamano, EAF, and BF

Disinfectants are [antimicrobial agents](#) that are applied to non-living objects to destroy [microorganisms](#) that are living on the objects.^[1] Disinfection does not necessarily kill all microorganisms, especially resistant [bacterial spores](#); it is less effective than [sterilization](#), which is an extreme physical and/or chemical process that kills all types of life.^[1] Disinfectants are different from other antimicrobial agents such as [antibiotics](#), which destroy microorganisms within the body, and [antiseptics](#), which destroy microorganisms on living [tissue](#). Disinfectants are also different from [biocides](#) — the latter are intended to destroy all forms of life, not just microorganisms. Disinfectants work by destroying the cell wall of microbes or interfering with the metabolism.

[Sanitizers](#) are substances that simultaneously clean and disinfect.^[2]

Bacterial [endospores](#) are most resistant to disinfectants, but some viruses and bacteria also possess some tolerance.

Disinfectants are frequently used in hospitals, dental surgeries, kitchens, and bathrooms to kill infectious organisms.

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Properties

A perfect disinfectant would also offer complete and full microbiological [sterilisation](#), without harming humans and useful forms of life, be inexpensive, and non-corrosive. However, most disinfectants are also, by nature, potentially harmful (even [toxic](#)) to humans or animals. Most modern household disinfectants contain [Bitrex](#), an exceptionally bitter substance added to discourage ingestion, as a safety measure. Those that are used indoors should never be mixed with other cleaning products as [chemical reactions](#) can occur.^[3] The choice of disinfectant to be used depends on the particular situation. Some disinfectants have a wide spectrum (kill many different types of microorganisms), while others kill a smaller range of disease-causing organisms but are preferred for other properties (they may be non-corrosive, non-toxic, or inexpensive).^[4] There are arguments for creating or maintaining conditions that are not conducive to bacterial survival and multiplication, rather than attempting to kill them with chemicals. Bacteria can increase in number very quickly, which enables them to [evolve](#) rapidly. Should some bacteria survive a chemical attack, they give rise to new generations composed completely of bacteria that have resistance to the particular chemical used. Under a sustained chemical attack, the surviving bacteria in successive generations are increasingly resistant to the chemical used, and ultimately the chemical is rendered ineffective. For this reason, some question the wisdom of impregnating cloths, [cutting boards](#) and worktops in the home with [bactericidal](#) chemicals. [citation needed]

Types

Air disinfectants

Air disinfectants are typically chemical substances capable of disinfecting microorganisms suspended in the air. Disinfectants are generally assumed to be limited to use on surfaces, but that is not the case. In 1928, a study found that airborne microorganisms could be killed using mists of dilute bleach.^[5] An air disinfectant must be dispersed either as an [aerosol](#) or [vapour](#) at a sufficient

concentration in the air to cause the number of viable infectious microorganisms to be significantly reduced.

In the 1940s and early 1950s, further studies showed inactivation of diverse [bacteria](#), [influenza virus](#), and [Penicillium chrysogenum](#) (previously *P. notatum*) [mold fungus](#) using various glycols, principally [propylene glycol](#) and [triethylene glycol](#).^[6] In principle, these chemical substances are ideal air disinfectants because they have both high lethality to microorganisms and low mammalian toxicity.^{[7][8]}

Although glycols are effective air disinfectants in controlled laboratory environments, it is more difficult to use them effectively in real-world environments because the disinfection of air is sensitive to continuous action. Continuous action in real-world environments with outside air exchanges at door, HVAC, and window interfaces, and in the presence of materials that adsorb and remove glycols from the air, poses engineering challenges that are not critical for surface disinfection. The engineering challenge associated with creating a sufficient concentration of the glycol vapours in the air have not to date been sufficiently addressed.^{[9][10]}

Alcohols[

[Alcohols](#), usually [ethanol](#) or [isopropanol](#), are sometimes used as a disinfectant, but more often as an [antiseptic](#)^[citation needed] (the distinction being that alcohol tends to be used on living tissue rather than nonliving surfaces).^[citation needed] They are non-corrosive, but can be a fire hazard. They also have limited residual activity due to evaporation, which results in brief contact times unless the surface is submerged, and have a limited activity in the presence of organic material.^[citation needed] Alcohols are most effective when combined with purified water to facilitate diffusion through the cell membrane; 100% alcohol typically denatures only external membrane proteins.^[11] A mixture of 70% ethanol or isopropanol diluted in water is effective against a wide spectrum of bacteria, though higher concentrations are often needed to disinfect wet surfaces.^[12] Additionally, high-concentration mixtures (such as 80% ethanol + 5% isopropanol) are required to effectively inactivate lipid-enveloped viruses (such as HIV, hepatitis B, and hepatitis C).^{[11][12][13][13][14]} The efficacy of alcohol is enhanced when in solution with the wetting agent [dodecanoic acid](#) (coconut soap). The synergistic effect of 29.4% ethanol with dodecanoic acid is effective against a broad spectrum of bacteria, fungi, and viruses. Further testing is being performed against *Clostridium difficile* (C.Diff) spores with higher concentrations of ethanol and dodecanoic acid, which proved effective with a contact time of ten minutes.^[15]

Aldehydes[

[Aldehydes](#), such as [formaldehyde](#) and [glutaraldehyde](#), have a wide microbicidal activity and are [sporocidal](#) and [fungicidal](#). They are partly inactivated by organic matter and have slight residual activity.

Some bacteria have developed resistance to glutaraldehyde, and it has been found that glutaraldehyde can cause asthma and other health hazards, hence [ortho-phthalaldehyde](#) is replacing glutaraldehyde.^[citation needed]

Oxidizing agents

[Oxidizing agents](#) act by oxidizing the cell membrane of microorganisms, which results in a loss of structure and leads to cell [lysis](#) and death. A large number of disinfectants operate in this way. [Chlorine](#) and [oxygen](#) are strong oxidizers, so their compounds figure heavily here.

- [Sodium hypochlorite](#) is very commonly used. Common household [bleach](#) is a sodium hypochlorite solution and is used in the home to disinfect drains, [toilets](#), and other surfaces. In more dilute form, it is used in swimming pools, and in still more dilute form, it is used in drinking water. When pools and drinking water are said to be chlorinated, it is actually sodium hypochlorite or a related compound—not pure chlorine—that is being used. Chlorine partly reacts with proteinaceous liquids such as blood to form non-oxidizing N-chloro compounds, and thus higher concentrations must be used if disinfecting surfaces after blood spills.^[16] Commercial solutions with higher concentrations contain substantial amounts of [sodium hydroxide](#) for stabilization of the concentrated hypochlorite, which would otherwise decompose to chlorine, but the solutions are strongly basic as a result.
- Other hypochlorites such as [calcium hypochlorite](#) are also used, especially as a swimming pool additive. Hypochlorites yield an aqueous solution of [hypochlorous acid](#) that is the true disinfectant. Hypobromite solutions are also sometimes used.
- [Electrolyzed water](#) or "Anolyte" is an oxidizing, acidic hypochlorite solution made by [electrolysis](#) of [sodium chloride](#) into [sodium hypochlorite](#) and hypochlorous acid. Anolyte has an oxidation-reduction potential of +600 to +1200 mV and a typical pH range of 3.5—8.5, but the most potent solution is produced at a controlled pH 5.0–6.3 where the predominant oxychlorine species is [hypochlorous acid](#).
- [Chloramine](#) is often used in drinking water treatment.
- [Chloramine-T](#) is antibacterial even after the chlorine has been spent, since the parent compound is a [sulfonamide antibiotic](#).
- [Chlorine dioxide](#) is used as an advanced disinfectant for drinking water to reduce waterborne diseases. In certain parts of the world, it has largely replaced chlorine because it forms fewer byproducts. [Sodium chlorite](#), [sodium chlorate](#), and [potassium chlorate](#) are used as precursors for generating chlorine dioxide.
- [Hydrogen peroxide](#) is used in [hospitals](#) to disinfect surfaces and it is used in solution alone or in combination with other chemicals as a high level disinfectant. Hydrogen peroxide is sometimes mixed with [colloidal silver](#). It is often preferred because it causes far fewer [allergic](#) reactions than

alternative disinfectants. Also used in the food packaging industry to disinfect foil containers. A 3% solution is also used as an antiseptic.

- [Hydrogen peroxide vapor](#) is used as a [medical sterilant](#) and as room disinfectant. Hydrogen peroxide has the advantage that it decomposes to form oxygen and water thus leaving no long term residues, but hydrogen peroxide as with most other strong oxidants is hazardous, and solutions are a primary irritant. The vapor is hazardous to the respiratory system and eyes and consequently the [OSHA](#) permissible exposure limit is 1 ppm (29 CFR 1910.1000 Table Z-1) calculated as an eight hour time weighted average and the [NIOSH](#) immediately dangerous to life and health limit is 75 ppm.^[17] Therefore, engineering controls, personal protective equipment, gas monitoring etc. should be employed where high concentrations of hydrogen peroxide are used in the workplace. Vaporized hydrogen peroxide is one of the chemicals approved for decontamination of anthrax spores from contaminated buildings, such as occurred during the [2001 anthrax attacks](#) in the U.S. It has also been shown to be effective in removing exotic animal viruses, such as avian influenza and [Newcastle disease](#) from equipment and surfaces.
- The antimicrobial action of hydrogen peroxide can be enhanced by [surfactants](#) and organic acids. The resulting chemistry is known as Accelerated Hydrogen Peroxide. A 2% solution, stabilized for extended use, achieves high-level disinfection in 5 minutes, and is suitable for disinfecting medical equipment made from hard plastic, such as in [endoscopes](#).^[18] The evidence available suggests that products based on Accelerated Hydrogen Peroxide, apart from being good germicides, are safer for humans and benign to the environment.^[19]
- [Iodine](#) is usually dissolved in an organic solvent or as [Lugol's iodine](#) solution. It is used in the [poultry](#) industry. It is added to the birds' drinking water. In human and veterinary medicine, iodine products are widely used to prepare incision sites prior to surgery. Although it increases both scar tissue formation and healing time, [tincture of iodine](#) is used as an antiseptic for skin cuts and scrapes, and remains among the most effective antiseptics known.^[citation needed] Also used as an [iodophor](#)
- [Ozone](#) is a gas used for disinfecting water, laundry, foods, air, and surfaces. It is chemically aggressive and destroys many organic compounds, resulting in rapid decolorization and deodorization in addition to disinfection. Ozone decomposes relatively quickly. However, due to this characteristic of ozone, tap water chlorination cannot be entirely replaced by ozonation, as the ozone would decompose already in the water piping. Instead, it is used to remove the bulk of oxidizable matter from the water, which would produce small amounts of [organochlorides](#) if treated with chlorine only. Regardless, ozone has a very wide range of applications from municipal to industrial water treatment due to its powerful reactivity.
- [Peracetic acid](#) is a disinfectant produced by reacting hydrogen peroxide with acetic acid. It is broadly effective against microorganisms and is not deactivated by [catalase](#) and [peroxidase](#), the enzymes that break down hydrogen peroxide. It also breaks down to food safe and environmentally friendly residues (acetic acid and hydrogen peroxide), and therefore can be

used in non-rinse applications. It can be used over a wide temperature range (0-40 °C), wide pH range (3.0-7.5), in [clean-in-place](#) (CIP) processes, in [hard water](#) conditions, and is not affected by protein residues.

- [Performic acid](#) is the simplest and most powerful perorganic acid. Formed from the reaction of hydrogen peroxide and formic acid, it reacts more rapidly and powerfully than peracetic acid before breaking down to water and carbon dioxide.
- [Potassium permanganate](#) (KMnO₄) is a purplish-black crystalline powder that colours everything it touches, through a strong oxidising action. This includes staining "stainless" steel, which somehow limits its use and makes it necessary to use plastic or glass containers. It is used to disinfect [aquariums](#) and is also widely used in community swimming pools to disinfect ones feet before entering the pool. Typically, a large shallow basin of KMnO₄/water solution is kept near the pool ladder. Participants are required to step in the basin and then go into the pool. Additionally, it is widely used to disinfect community water ponds and wells in tropical countries, as well as to disinfect the mouth before pulling out teeth. It can be applied to wounds in dilute solution.
- [Potassium peroxymonosulfate](#), the principal ingredient in [Virkon](#), is a wide-spectrum disinfectant used in laboratories. [Virkon](#) kills bacteria, viruses, and fungi. It is used as a 1% solution in water, and keeps for one week once it is made up. It is expensive, but very effective, its pink colour fades as it is used up so it is possible to see at a glance if it is still fresh.

Phenolics [\[edit\]](#)

[Phenolics](#) are active ingredients in some household disinfectants. They are also found in some mouthwashes and in disinfectant soap and handwashes.

- [Phenol](#) is probably the oldest known disinfectant as it was first used by [Lister](#), when it was called carbolic acid. It is rather corrosive to the skin and sometimes toxic to sensitive people. Impure preparations of phenol were originally made from [coal tar](#), and these contained low concentrations of other [aromatic hydrocarbons](#) including [benzene](#), which is an [IARC Group 1 carcinogen](#).
- [o-Phenylphenol](#) is often used instead of [phenol](#), since it is somewhat less corrosive.
- [Chloroxylenol](#) is the principal ingredient in [Dettol](#), a household disinfectant and [antiseptic](#).
- [Hexachlorophene](#) is a phenolic that was once used as a germicidal additive to some household products but was banned due to suspected harmful effects.
- [Thymol](#), derived from the herb thyme, is the active ingredient in some "broad spectrum" disinfectants that bears ecological claims.
- [Amylmetacresol](#) is found in [Strepsils](#), a throat disinfectant.
- Although not a phenol, [2,4-dichlorobenzyl alcohol](#) has similar effects as phenols, but it cannot inactivate viruses.

Quaternary ammonium compounds^[edit]

[Quaternary ammonium compounds](#) ("quats"), such as [benzalkonium chloride](#), are a large group of related compounds. Some concentrated formulations have been shown to be effective low-level disinfectants. Typically, quats do not exhibit efficacy against difficult to kill non-enveloped viruses such as [norovirus](#), [rotavirus](#), or [polio virus](#). Newer synergous, low-alcohol formulations are highly effective broad-spectrum disinfectants with quick contact times (3–5 minutes) against bacteria, enveloped viruses, pathogenic fungi, and [mycobacteria](#). Quats are biocides that also kill algae and are used as an additive in large-scale industrial water systems to minimize undesired biological growth.

Silver^[edit]

[Silver](#) has antimicrobial properties, but compounds suitable for disinfection are usually unstable and have a limited shelf-life. [Silver dihydrogen citrate](#) (SDC) is a chelated form of silver that maintains its stability. SDC kills microorganisms by two modes of action: 1) the silver ion deactivates structural and metabolic membrane proteins, leading to microbial death; 2) the microbes view SDC as a food source, allowing the silver ion to enter the microbe. Once inside the organism, the silver ion denatures the DNA, which halts the microbe's ability to replicate, leading to its death. This dual action makes SDC highly and quickly effective against a broad spectrum of microbes. SDC is non-toxic, non-caustic, colorless, odorless, and tasteless, and does not produce toxic fumes. SDC is non-toxic to humans and animals: the [United States Environmental Protection Agency](#) classifies it into the lowest toxicity category for disinfectants, category IV.

A meta-analysis of 26 studies by the [Cochrane Collaboration](#) found that, most were small and of poor quality, and that there was not enough evidence to support the use of silver-containing dressings or creams, as generally these treatments did not promote wound healing or prevent wound infections. Some evidence suggested that silver sulphadiazine had no effect on infection, and actually slowed healing.^[20]

Copper alloy surfaces^[edit]

Main articles: [Antimicrobial properties of copper](#) and [Antimicrobial copper-alloy touch surfaces](#)

Copper-alloy surfaces have natural intrinsic properties to destroy a wide range of [microorganisms](#) (e.g., [E. coli](#) O157:H7, [methicillin-resistant Staphylococcus aureus](#) (MRSA), [Staphylococcus](#), [Clostridium difficile](#), [influenza A virus](#), [adenovirus](#), and [fungi](#)). In addition, extensive tests on [E. coli](#) O157:H7, [methicillin-resistant Staphylococcus aureus](#) (MRSA), [Staphylococcus](#), [Enterobacter aerogenes](#), and [Pseudomonas aeruginosa](#) sanctioned by the [United States Environmental Protection Agency](#) (EPA) using Good Laboratory Practices found that when cleaned regularly, some 355 different copper alloy surfaces:

- [Continuously reduce bacterial contamination, achieving 99.9% reduction within two hours of exposure;](#)
- [Kill greater than 99.9% of Gram-negative and Gram-positive bacteria within two hours of exposure;](#)
- [Deliver continuous and ongoing antibacterial action, remaining effective in killing greater than 99.9% of bacteria within two hours;](#)
- [Kill greater than 99.9% of bacteria within two hours, and continue to kill 99% of bacteria even after repeated contamination;](#)
- [Help inhibit the buildup and growth of bacteria within two hours of exposure between routine cleaning and sanitizing steps.](#) ^[citation needed]

These copper alloys were granted [EPA registrations](#) as “antimicrobial materials with public health benefits,”^[21] which allows manufacturers to legally make claims regarding the positive public health benefits of products made with [registered antimicrobial copper alloys](#). EPA has approved a long list of antimicrobial copper products made from these alloys, such as bedrails, [handrails](#), over-bed tables, [sinks](#), [faucets](#), [door knobs](#), [toilet](#) hardware, [computer keyboards](#), [health club](#) equipment, [shopping cart](#) handles, etc. (for a comprehensive list of products, see: [Antimicrobial copper-alloy touch surfaces#Approved products](#)). Antimicrobial copper alloy products are now being installed in healthcare facilities in the U.K., Ireland, Japan, Korea, France, Denmark, and Brazil and in the subway transit system in Santiago, Chile, where copper-zinc alloy handrails will be installed in some 30 stations between 2011 and 2014.^{[22][23]}

Other[\[edit\]](#)

The [biguanide polymer polyaminopropyl biguanide](#) is specifically bactericidal at very low concentrations (10 mg/l). It has a unique method of action: The polymer strands are incorporated into the bacterial cell wall, which disrupts the membrane and reduces its permeability, which has a lethal effect to bacteria. It is also known to bind to bacterial DNA, alter its transcription, and cause lethal DNA damage.^[24] It has very low toxicity to higher organisms such as human cells, which have more complex and protective membranes.

[Ultraviolet germicidal irradiation](#) is the use of high-intensity shortwave [ultraviolet light](#) for disinfecting smooth surfaces such as dental tools, but not porous materials that are opaque to the light such as wood or foam. Ultraviolet light is also used for municipal [water treatment](#). Ultraviolet light fixtures are often present in [microbiology](#) labs, and are activated only when there are no occupants in a room (e.g., at night).

Common [sodium bicarbonate](#) (NaHCO₃) has antifungal properties,^[25] and some antiviral and antibacterial properties,^[26] though those are too weak to be effective at a home environment.^[27]

[Lactic acid](#) is a registered disinfectant. Due to its natural and environmental profile, it has gained importance in the market.

Measurements of effectiveness^[edit]

One way to compare disinfectants is to compare how well they do against a known disinfectant and rate them accordingly. Phenol is the standard, and the corresponding rating system is called the "[Phenol coefficient](#)". The disinfectant to be tested is compared with phenol on a standard microbe (usually *Salmonella typhi* or *Staphylococcus aureus*). Disinfectants that are more effective than phenol have a coefficient > 1. Those that are less effective have a coefficient < 1.

The standard European approach for disinfectant validation consists of a basic suspension test, a quantitative suspension test (with low and high levels of organic material added to act as 'interfering substances') and a two part simulated-use surface test.^[28]

A less specific measurement of effectiveness is the [United States Environmental Protection Agency](#) (EPA) classification into either *high*, *intermediate* or *low* levels of disinfection. "High-level disinfection kills all organisms, except high levels of bacterial spores" and is done with a chemical germicide marketed as a sterilant by the U.S. [Food and Drug Administration](#) (FDA). "Intermediate-level disinfection kills mycobacteria, most viruses, and bacteria with a chemical germicide registered as a 'tuberculocide' by the Environmental Protection Agency. Low-level disinfection kills some viruses and bacteria with a chemical germicide registered as a hospital disinfectant by the EPA."^[29]

An alternative assessment is to measure the Minimum inhibitory concentrations (MICs) of disinfectants against selected (and representative) microbial species, such as through the use of microbroth dilution testing.^[30]

Home disinfectants^[edit]



Doors at the [Hong Kong Museum of History](#) with signage stating that the doors are disinfected frequently.

By far the most cost-effective home disinfectant is the commonly used chlorine bleach (a 5% solution of [sodium hypochlorite](#)), which is effective against most common [pathogens](#), including difficult organisms such as [tuberculosis](#) (*mycobacterium tuberculosis*), [hepatitis](#) B and C, [fungi](#), and antibiotic-resistant strains of [staphylococcus](#) and [enterococcus](#). It even has some disinfectant action against parasitic organisms.^[31]

Positives are that it kills the widest range of pathogens of any inexpensive disinfectant, is extremely powerful against viruses and bacteria at room temperature, is commonly available and inexpensive, and breaks down quickly into harmless components (primarily table salt and oxygen).^[citation needed]

Negatives are that it is caustic to the skin, lungs, and eyes (especially at higher concentrations); like many common disinfectants, it degrades in the presence of organic substances; it has a strong odor; it is not effective against *Giardia lamblia* and *Cryptosporidium*; and extreme caution must be taken not to combine it with ammonia or any acid (such as *vinegar*), as this can cause noxious gases to be formed. The best practice is not to add anything to household bleach except water. Dilute bleach can be tolerated on the skin for a period of time by most persons.^[citation needed]

To use chlorine bleach effectively, the surface or item to be disinfected must be clean. In the bathroom or when cleaning after pets, special caution must be taken to wipe up urine first, before applying chlorine, to avoid reaction with the ammonia in urine, causing toxic gas by-products. A 1-to-20 solution in water is effective simply by being wiped on and left to dry. The user should wear rubber gloves and, in tight airless spaces, goggles. If parasitic organisms are suspected, it should be applied at 1-to-1 concentration, or even undiluted. Extreme caution must be taken to avoid contact with eyes and mucous membranes. Protective goggles and good ventilation are mandatory when applying concentrated bleach.^[citation needed]

Commercial bleach tends to lose strength over time, whenever the container is opened. Old containers of partially used bleach may no longer have the labeled concentration.^[citation needed]

Where one does not want to risk the corrosive effects of bleach, alcohol-based disinfectants are reasonably inexpensive and quite safe. The great drawback to them is their rapid evaporation; sometimes effective disinfection can be obtained only by immersing an object in the alcohol.^[citation needed]

The use of some antimicrobials such as *triclosan*, in particular in the uncontrolled home environment, is controversial because it may lead to the germs becoming resistant. Chlorine bleach and alcohol do not cause resistance because they are so completely lethal, in a very direct physical way

Industrial processes are procedures involving *chemical*, *physical*, *electrical* or *mechanical* steps to aid in the *manufacture* of an item or items, usually carried out on a very large scale. Industrial processes are the key components of *heavy industry*.

The Haber process creates Ammonia (NH₄)

• • •

The Haber process takes nitrogen from the air and combines it with hydrogen from natural gas.

. . .

The Haber process takes hydrogen from natural gas and combines it with nitrogen from the air.

. . .

The Haber process uses ___ volume of nitrogen to _____ volumes of hydrogen. one, three.

. . .

The Haber process takes place at 500 degrees.

. . .

The Haber process takes place at a pressure of 200 atm

. . .

In the Haber Process the catalyst is iron.

. . .

In the Haber Process the forward reaction should be favoured by a low temperature and a high pressure.

. . .

Ammonia is used to make fertilisers, nitric acid and nylon.

. . .

The Contact process is the process of making sulphur trioxide

. . .

In the Contact Process, sulphur dioxide is produced by burning sulphur or sulphide ores in the air.

. . .

In the Contact Process the sulphur dioxide is converted using an excess of air (oxygen).

. . .

In the Contact Process the sulphur dioxide is converted at a temperature of 450 degrees.

. . .

In the Contact Process the catalyst used is vanadium (V) oxide