

Ethanol

“Drinking alcohol” redirects here. For information related to the consumption of alcohol, see **Alcoholic beverage**.

For other uses, see **Ethanol (disambiguation)**.

Ethanol /ˈɛθənɒl/, also commonly called **ethyl alcohol**, **drinking alcohol**, or simply **alcohol** is the principal type of alcohol found in alcoholic beverages, produced by the fermentation of sugars by yeasts. It is a neurotoxic^{[14][15]} psychoactive drug and one of the oldest recreational drugs used by humans. It can cause alcohol intoxication when consumed in sufficient quantity.

Ethanol is a volatile, flammable, colorless liquid with a slight chemical odor. It is used as an antiseptic, a solvent, a fuel, and, due to its low freezing point, the active fluid in post-mercury thermometers. The molecule is a simple one, being an ethyl group linked to a hydroxyl group. Its structural formula, CH

3CH

2OH, is often abbreviated as C

2H

5OH, C

2H

6O or **EtOH**.

The stem word “eth-” used in many related compounds originates with the German word for ethanol (*äthyl*).^[16]

1 Etymology

Ethanol is the systematic name defined by the International Union of Pure and Applied Chemistry (IUPAC) for a molecule with two carbon atoms (prefix “eth-”), having a single bond between them (suffix “-ane”), and an attached functional group-OH group (suffix “-ol”).^[1]

The prefix *ethyl* was coined in 1834 by the German chemist Justus Liebig.^[17] *Ethyl* is a contraction of the Ancient Greek αἰθήρ (aithér, “upper air”) and the Greek word ὕλη (*hyle*, substance).^[18]

The name *ethanol* was coined as a result of a resolution that was adopted at the International Conference on Chemical Nomenclature that was held in April 1892 in Geneva, Switzerland.^[19]

The term “alcohol” now refers to a wider class of substances in chemistry nomenclature, but in common parlance it remains the name of ethanol. Ultimately a me-

dieval loan from Arabic *al-kuḥl*,^[20] use of *alcohol* in this sense is modern, introduced in the mid 18th century. Before that time, Middle Latin *alcohol* referred to “powdered ore of antimony; powdered cosmetic”, by the later 17th century “any sublimated substance; distilled spirit” use for “the spirit of wine” (shortened from a full expression *alcohol of wine*) recorded 1753. The systematic use in chemistry dates to 1850.

2 Chemical formula

Ethanol is a 2-carbon alcohol. Its molecular formula is CH₃CH₂OH. An alternative notation is CH₃–CH₂–OH, which indicates that the carbon of a methyl group (CH₃–) is attached to the carbon of a methylene group (–CH₂–), which is attached to the oxygen of a hydroxyl group (–OH). It is a constitutional isomer of dimethyl ether. Ethanol is sometimes abbreviated as **EtOH**, using the common organic chemistry notation of representing the ethyl group (C₂H₅-) with **Et**.

3 Uses

3.1 Medical

3.1.1 Antiseptic

Ethanol is used in medical wipes and in most common antibacterial hand sanitizer gels at a concentration of about 62% v/v as an antiseptic. Ethanol kills organisms by denaturing their proteins and dissolving their lipids and is effective against most bacteria and fungi, and many viruses. But ethanol is ineffective against bacterial spores.^[21]

3.1.2 Antitussive

Ethanol is widely used, clinically and over the counter, as an antitussive agent.^[22]

3.1.3 Antidote

Ethanol may be administered as an antidote to methanol^[23] and ethylene glycol poisoning.

3.1.4 Medicinal solvent

Ethanol, often in surprisingly high concentrations, is used to dissolve many water-insoluble medications and related compounds. Proprietary liquid preparations of cough and cold remedies, analgesics, and mouth washes may be dissolved in 1 to 25% concentrations of ethanol and may need to be avoided in individuals with adverse reactions to ethanol such as alcohol-induced respiratory reactions.^[24]

3.2 Recreational

Ethanol is a central nervous system depressant and has significant psychoactive effects in sublethal doses. Based on its abilities to alter human consciousness, ethanol is considered a psychoactive drug.^[25]

The amount of ethanol in the body is typically quantified by blood alcohol content (BAC), which is here taken as weight of ethanol per unit volume of blood. Small doses of ethanol, in general, produce euphoria and relaxation; people experiencing these symptoms tend to become talkative and less inhibited, and may exhibit poor judgment. At higher dosages (BAC > 1 g/L), ethanol acts as a central nervous system depressant, producing at progressively higher dosages, impaired sensory and motor function, slowed cognition, stupefaction, unconsciousness, and possible death. Ethanol is commonly consumed as a recreational drug, especially while socializing, due to its psychoactive effects.

3.3 Fuel

3.3.1 Engine fuel

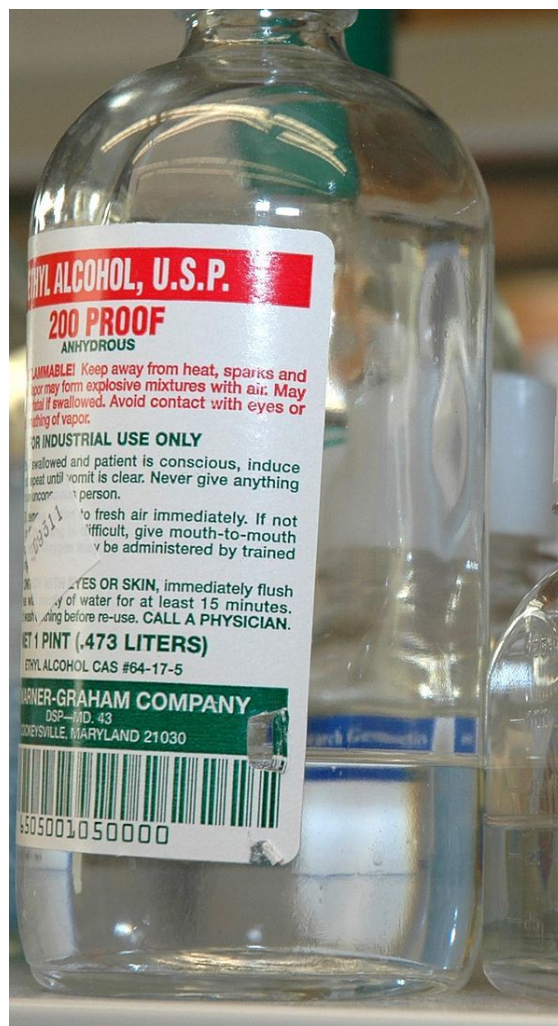
Main article: Ethanol fuel

The largest single use of ethanol is as an engine fuel and fuel additive. Brazil in particular relies heavily upon the use of ethanol as an engine fuel, due in part to its role as the globe's leading producer of ethanol.^[30] Gasoline sold in Brazil contains at least 25% anhydrous ethanol. Hydrous ethanol (about 95% ethanol and 5% water) can be used as fuel in more than 90% of new gasoline fueled cars sold in the country. Brazilian ethanol is produced from sugar cane and noted for high carbon sequestration.^[31] The US uses Gasohol (max 10% ethanol) and E85 (85% ethanol) ethanol/gasoline mixtures.

Ethanol has been used as rocket fuel and is currently in lightweight rocket-powered racing aircraft.^[32]

Australian law limits the use of pure ethanol from sugarcane waste to 10% in automobiles. Older cars (and vintage cars designed to use a slower burning fuel) should have the engine valves upgraded or replaced.^[33]

According to an industry advocacy group, ethanol as a fuel reduces harmful tailpipe emissions of carbon monox-



USP grade ethanol for laboratory use.

ide, particulate matter, oxides of nitrogen, and other ozone-forming pollutants.^[34] Argonne National Laboratory analyzed greenhouse gas emissions of many different engine and fuel combinations, and found that biodiesel/petrodiesel blend (B20) showed a reduction of 8%, conventional E85 ethanol blend a reduction of 17% and cellulosic ethanol 64%, compared with pure gasoline.^[35]

Ethanol combustion in an internal combustion engine yields many of the products of incomplete combustion produced by gasoline and significantly larger amounts of formaldehyde and related species such as acetaldehyde.^[36] This leads to a significantly larger photochemical reactivity and more ground level ozone.^[37] These data have been assembled into The Clean Fuels Report comparison of fuel emissions^[38] and show that ethanol exhaust generates 2.14 times as much ozone as gasoline exhaust. When this is added into the custom *Localised Pollution Index (LPI)* of The Clean Fuels Report, the local pollution of ethanol (pollution that contributes to smog) is rated 1.7, where gasoline is 1.0 and higher numbers signify greater pollution. The California Air Re-

sources Board formalized this issue in 2008 by recognizing control standards for formaldehydes as an emissions control group, much like the conventional NO_x and Reactive Organic Gases (ROGs).^[39]

World production of ethanol in 2006 was 51 giga litres (1.3×10^{10} US gal), with 69% of the world supply coming from Brazil and the United States.^[40] More than 20% of Brazilian cars are able to use 100% ethanol as fuel, which includes ethanol-only engines and flex-fuel engines.^[41] Flex-fuel engines in Brazil are able to work with all ethanol, all gasoline or any mixture of both. In the US flex-fuel vehicles can run on 0% to 85% ethanol (15% gasoline) since higher ethanol blends are not yet allowed or efficient. Brazil supports this population of ethanol-burning automobiles with large national infrastructure that produces ethanol from domestically grown sugar cane. Sugar cane not only has a greater concentration of sucrose than corn (by about 30%), but is also much easier to extract. The *bagasse* generated by the process is not wasted, but is used in power plants to produce electricity.

In the United States, the ethanol fuel industry is based largely on corn. According to the Renewable Fuels Association, as of 30 October 2007, 131 grain ethanol biorefineries in the United States have the capacity to produce 7.0 billion US gallons ($26,000,000 \text{ m}^3$) of ethanol per year. An additional 72 construction projects underway (in the U.S.) can add 6.4 billion US gallons ($24,000,000 \text{ m}^3$) of new capacity in the next 18 months. Over time, it is believed that a material portion of the ≈ 150 -billion-US-gallon ($570,000,000 \text{ m}^3$) per year market for gasoline will begin to be replaced with fuel ethanol.^[42]

Sweet sorghum is another potential source of ethanol, and is suitable for growing in dryland conditions. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is investigating the possibility of growing sorgham as a source of fuel, food, and animal feed in arid parts of Asia and Africa.^[43] Sweet sorghum has one-third the water requirement of sugarcane over the same time period. It also requires about 22% less water than corn (also known as maize). The world's first sweet sorghum ethanol distillery began commercial production in 2007 in Andhra Pradesh, India.^[44]

Ethanol's high miscibility with water makes it unsuitable for shipping through modern pipelines like liquid hydrocarbons.^[45] Mechanics have seen increased cases of damage to small engines (in particular, the carburetor) and attribute the damage to the increased water retention by ethanol in fuel.^[46]



Ethanol pump station in São Paulo, Brazil



A Ford Taurus fueled by ethanol in New York City



USPS truck running on E85 in Minnesota

3.3.2 Rocket Fuel

Ethanol was commonly used as fuel in early bipropellant rocket (liquid propelled) vehicles, in conjunction with an oxidizer such as liquid oxygen. The German V-2 rocket of World War II, credited with beginning the space age, used ethanol, mixed with 25% of water to reduce the combustion chamber temperature.^{[47][48]} The V-2's design team helped develop U.S. rockets following World War II, including the ethanol-fueled Redstone rocket which launched the first U.S. satellite.^[49] Alcohols fell into general disuse as more efficient rocket fuels were developed.^[48]

3.3.3 Fuel Cells

Commercial fuel cells operate on reformed natural gas, hydrogen or methanol. Ethanol is an attractive alternative due to its wide availability, low cost, high purity and low toxicity. There are a wide range of fuel cell concepts that have been trialed including direct-ethanol fuel cells, auto-thermal reforming systems and thermally integrated systems. The majority of work is being conducted

at a research level although there are a number of organizations at the beginning of commercialization of ethanol fuel cells.^[50]

3.3.4 Household heating



An example of a bio-ethanol fire in the form of a traditional fireplace, using fire-proof ceramic simulated wood logs for effect.

Ethanol fuels flue-less, real flame fireplaces.^[51] Ethanol is kept in a burner containing a wick such as glass wool, a safety shield to reduce the chances of accidents and an extinguisher such as a plate or shutter to cut off oxygen.

It provides almost the same visual benefits of a real flame log or coal fire without the need to vent the fumes via a flue as ethanol produces very little hazardous carbon monoxide, and little or no noticeable scent. It does emit carbon dioxide and requires oxygen. Therefore, external ventilation of the room containing the fire is needed to ensure safe operation.

An additional benefit is that, unlike a flue based fireplace, 100% of the heat energy produced enters the room. This serves to offset some of the heat loss from an external air vent, as well as offset the relatively high cost of the fuel compared to other forms of heating.

3.4 Feedstock

Further information: § Reactions

Ethanol is an important industrial ingredient. It has widespread use as a precursor for other organic compounds such as ethyl halides, ethyl esters, diethyl ether, acetic acid, and ethyl amines.

3.5 Solvent

Ethanol is miscible with water and is a good general purpose solvent. It is found in paints, tinctures, markers, and personal care products such as mouthwashes, perfumes and deodorants. However, polysaccharides precipitate

from aqueous solution in the presence of alcohol, and ethanol precipitation is used for this reason in the purification of DNA and RNA.

4 Adverse effects

Main articles: Alcohol and health and Short-term effects of alcohol

4.1 Loss of balance

When alcohol reaches the brain, it has the ability to delay signals that are sent between nerve cells that control balance, thinking and movement.^[52]

4.2 Gastrointestinal diseases

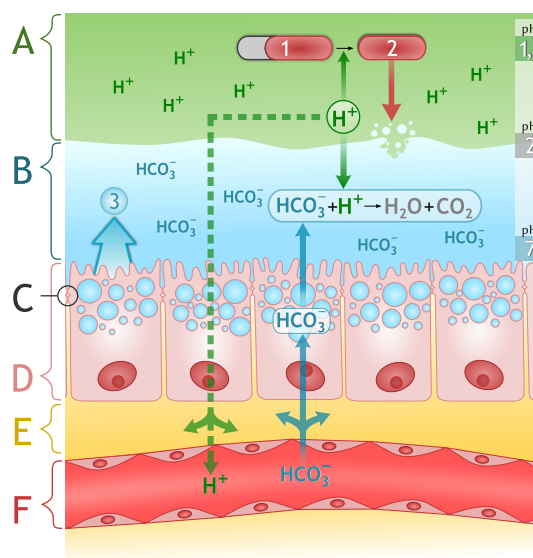


Diagram of mucosal layer

Alcohol stimulates gastric juice production, even when food is not present. In other words, when a person drinks alcohol, the alcohol will stimulate stomach's acidic secretions that are intended to digest protein molecules. Consequently, the acidity has potential to harm the inner lining of the stomach. Normally, the stomach lining is protected by a mucus layer that prevents any acids from reaching the stomach cells.

However, in patients who have a peptic ulcer disease (PUD), this mucus layer is broken down. PUD is commonly associated with a bacteria *H. pylori*. *H. pylori* secretes a toxin that weakens the mucosal wall. As a result, acid and protein enzymes penetrate the weakened barrier. Because alcohol stimulates a person's stomach to secrete acid, a person with PUD should avoid drinking alcohol on an empty stomach. Drinking alcohol would

cause more acid release to damage the weakened stomach wall.^[53] Complications of this disease could include a burning pain in the abdomen, bloating and in severe cases, the presence of dark black stools indicate internal bleeding.^[54] A person who drinks alcohol regularly is strongly advised to reduce their intake to prevent PUD aggravation.^[54]

4.3 Short-term toxic allergy-like responses

Main articles: Alcohol-induced respiratory reactions and Alcohol flush reaction

Ethanol-containing beverages can cause urticarial skin eruptions, systemic dermatitis, alcohol flush reactions, exacerbations of rhinitis and, more seriously and commonly, bronchoconstriction in patients with a history of asthma. These reactions occur within 1–60 minutes of ethanol ingestion and are due to: **1)** genetic abnormalities in the metabolism of ethanol which cause the ethanol metabolite, acetaldehyde, to accumulate in tissues and trigger the release of histamine, the evoker of these symptoms; **2)** true allergy reactions to allergens occurring naturally in, or contaminating, alcoholic beverages, particularly wines and beers, and **3)** unknown causes.^[24]

4.4 Long-term

Main article: Long-term effects of alcohol

4.4.1 Birth defects

See also: fetal alcohol syndrome and fetal alcohol spectrum disorder

Ethanol is classified as a teratogen. According to the CDC, alcohol consumption by women of child-bearing age who are not using birth control increases the risk of fetal alcohol syndrome. The CDC currently recommends complete abstinence from alcoholic beverages.^[55]

4.4.2 Cancer

IARC list ethanol in alcoholic beverages as *Group 1 carcinogens* and arguments “There is sufficient evidence for the carcinogenicity of acetaldehyde (the major metabolite of ethanol) in experimental animals.”^[56]

4.4.3 Other effects

Frequent drinking of alcoholic beverages has been shown to be a major contributing factor in cases of elevated blood levels of triglycerides.^[57]

5 Overdose

See also: Alcohol consumption and health

Death from ethanol consumption is possible when blood alcohol levels reach 0.4%. A blood level of 0.5% or more is commonly fatal. Levels of even less than 0.1% can cause intoxication, with unconsciousness often occurring at 0.3–0.4%.^[59]

Prolonged heavy consumption of alcohol can cause significant permanent damage to the brain and other organs.

5.1 Addiction

See also: Alcoholism

The reinforcing effects of alcohol consumption are mediated by acetaldehyde generated by catalase and other oxidizing enzymes such as cytochrome P-4502E1 in the brain.^[60] Although acetaldehyde has been associated with some of the adverse and toxic effects of ethanol, it appears to play a central role in the activation of the mesolimbic dopamine system.^[61]

Ethanol’s rewarding and reinforcing (i.e., addictive) properties are mediated through its effects on dopamine neurons in the mesolimbic reward pathway, which connects the ventral tegmental area to the nucleus accumbens (NAcc).^{[62][63]} One of ethanol’s primary effects is the allosteric inhibition of NMDA receptors and facilitation of GABAA receptors (e.g., enhanced GABAA receptor-mediated chloride flux through allosteric regulation of the receptor).^[64] At high doses, ethanol inhibits most ligand gated ion channels and voltage gated ion channels in neurons as well.^[64]

With acute alcohol consumption, dopamine is released in the synapses of the mesolimbic pathway, in turn heightening activation of postsynaptic D1 receptors.^{[62][63]} The activation of these receptors triggers postsynaptic internal signaling events through protein kinase A which ultimately phosphorylate cAMP response element binding protein (CREB), inducing CREB-mediated changes in gene expression.^{[62][63]}

With chronic alcohol intake, consumption of ethanol similarly induces CREB phosphorylation through the D1 receptor pathway, but it also alters NMDA receptor function through phosphorylation mechanisms;^{[62][63]} an adaptive downregulation of the D1 receptor pathway and CREB function occurs as well.^{[62][63]} Chronic consumption is also associated with an effect on CREB phosphorylation and function via postsynaptic NMDA receptor signaling cascades through a MAPK/ERK pathway and CAMK-mediated pathway.^[63] These modifications to CREB function in the mesolimbic pathway induce expression (i.e., increase gene expression) of Δ FosB in the NAcc,^[63] where Δ FosB is the “master control protein”

that, when overexpressed in the NAcc, is necessary and sufficient for the development and maintenance of an addictive state (i.e., its overexpression in the nucleus accumbens produces and then directly modulates compulsive alcohol consumption).^{[63][65][66][67]}

5.2 Dependence and withdrawal

See also: Alcohol withdrawal syndrome

Discontinuing consumption of alcohol after several years of heavy drinking can also be fatal. Alcohol withdrawal can cause anxiety, autonomic dysfunction, seizures, and hallucinations. **Delirium tremens** is a condition that requires people with a long history of heavy drinking to undertake an alcohol detoxification regimen.

6 Interactions

Ethanol can intensify the sedation caused by other central nervous system depressant drugs such as barbiturates, benzodiazepines, opioids, non-benzodiazepines (such as Zolpidem and Zopiclone), antipsychotics, sedative antihistamines, and antidepressants.^[59] It interacts with cocaine in vivo to produce cocaethylene, another psychoactive substance.^[68] Ethanol enhances the bioavailability of methylphenidate (elevated plasma d-MPH).^[69] In combination with cannabis, ethanol increases plasma THC levels, which suggests that ethanol may increase the absorption of THC.^[70]

6.1 Alcohol and metronidazole

One of the most important drug/food interactions that should be noted is between alcohol and metronidazole.

Metronidazole is an antibacterial agent that kills bacteria by damaging cellular DNA and hence cellular function.^[71] Metronidazole is usually given to people who have diarrhea caused by *Clostridium difficile* bacteria. *C. difficile* is one of the most common microorganisms that cause diarrhea and can lead to complications such as colon inflammation and even more severely, death.

Patients who are taking metronidazole are strongly advised to avoid alcohol, even after 1 hour after the last dose. The reason is that alcohol and metronidazole can lead to side effects such as flushing, headache, nausea, vomiting, abdominal cramps, and sweating.^{[72][73][73]} These symptoms are often called the disulfiram-like reaction. The proposed mechanism of action for this interaction is that metronidazole can bind to an enzyme that normally metabolizes alcohol. Binding to this enzyme may impair the liver's ability to process alcohol for proper excretion.^[74]

7 Pharmacology

7.1 Pharmacodynamics

See also: Alcohol intoxication § Ethanol and GABAA Receptors and Calcium channel blocker § Ethanol

Ethanol acts in the central nervous system primarily by binding to the GABAA receptor, increasing the effects of the inhibitory neurotransmitter GABA (i.e., it is a positive allosteric modulator).^[75]

Ethanol is known to possess the following direct pharmacodynamic actions (most important actions are bolded):^[76]

- **GABAA receptor positive allosteric modulator** (primarily of δ subunit-containing receptors)
- Glycine receptor positive and negative allosteric modulator
- **NMDA receptor negative allosteric modulator**^[77]
- AMPA receptor negative allosteric modulator^[77]
- Kainate receptor negative allosteric modulator^[77]
- nACh receptor positive and negative allosteric modulator
- 5-HT₃ receptor positive allosteric modulator
- Glycine reuptake inhibitor^[78]
- Adenosine reuptake inhibitor^[79]
- L-type calcium channel blocker
- GIRK channel opener

Some of its actions on ligand-gated ion channels, specifically the nACh receptors and the glycine receptor, are dose-dependent, with potentiation *or* inhibition occurring dependent on ethanol concentration. This is because ethanol's effects on these channels are a summation of positive and negative allosteric modulatory actions.^[76]

7.2 Pharmacokinetics

The removal of ethanol from the human body, through oxidation by alcohol dehydrogenase in the liver, is limited. Hence, the removal of a large concentration of alcohol from blood may follow zero-order kinetics. This means that alcohol leaves the body at a constant rate, rather than having an elimination half-life.^[13]

The rate-limiting steps for one substance may be in common with other substances. As a result, the blood alcohol concentration can be used to modify the rate of

metabolism of **methanol** and **ethylene glycol**. Methanol itself is not highly toxic, but its metabolites **formaldehyde** and **formic acid** are; therefore, to reduce the rate of production and concentration of these harmful metabolites, ethanol can be ingested.^[80] **Ethylene glycol** poisoning can be treated in the same way.

Pure ethanol will irritate the skin and eyes.^[81] Nausea, vomiting and intoxication are symptoms of ingestion. Long-term use by ingestion can result in serious liver damage.^[82] Atmospheric concentrations above one in a thousand are above the European Union **Occupational exposure limits**.^[82]

7.2.1 Metabolism

Main articles: **Ethanol metabolism** and **Alcohol dehydrogenase**

Ethanol within the human body is converted into **acetaldehyde** by **alcohol dehydrogenase** and then into the **acetyl** in **acetyl CoA** by **acetaldehyde dehydrogenase**. **Acetyl CoA** is the final product of both carbohydrate and fat metabolism, where the **acetyl** can be further used to produce energy or for biosynthesis. As such, ethanol can be compared to an energy-bearing macronutrient, yielding approximately 7 kcal per gram consumed.^[83] However, the product of the first step of this breakdown, **acetaldehyde**,^[84] is more toxic than ethanol. **Acetaldehyde** is linked to most of the clinical effects of alcohol. It has been shown to increase the risk of developing cirrhosis of the liver^[85] and multiple forms of cancer.

During the metabolism of alcohol via the respective dehydrogenases, **NAD** (**Nicotinamide adenine dinucleotide**) is converted into reduced **NAD**. Normally, **NAD** is used to metabolise fats in the liver, and as such alcohol competes with these fats for the use of **NAD**. Prolonged exposure to alcohol means that fats accumulate in the liver, leading to the term 'fatty liver'. Continued consumption (such as in **alcoholism**) then leads to cell death in the hepatocytes as the fat stores reduce the function of the cell to the point of death. These cells are then replaced with scar tissue, leading to the condition called **cirrhosis**.

7.2.2 Alcohol and digestion

A part of ethyl alcohol is hydrophobic. This hydrophobic or lipophilic end can diffuse across cells that line the stomach wall. In fact, alcohol is one of the rare substances that can be absorbed in the stomach. Most food substances are absorbed in the small intestine. However, even though alcohol can be absorbed in the stomach, it is mostly absorbed in the small intestine because the small intestine has a large surface area that promotes absorption. Once alcohol is absorbed in the small intestine, it delays the release of stomach contents from emptying into the small intestine. Thus, alcohol can delay the rate

of absorption of nutrients.^[86] After absorption, alcohol reaches the liver where it is metabolized.

Breathalyzers

Alcohol that is not processed by the liver goes to the heart. The liver can process only a certain amount of alcohol per unit time. Thus, when a person drinks too much alcohol, more alcohol can reach the heart. In the heart, alcohol reduces the force of heart contractions. Consequently, the heart will pump less blood, lowering overall body blood pressure.^[52] Also, blood that reaches the heart goes to the lungs to replenish blood's oxygen concentration. It is at this stage that a person can breathe out traces of alcohol.^[52] This is the underlying principle of the alcohol breath testing (or breathalyzers) to determine if a driver has been drinking and driving.^[87]

From the lungs, blood returns to the heart and will be distributed throughout the body. Interestingly, alcohol increases levels of high-density lipoproteins (HDLs), which carry cholesterol.^[52] Alcohol is known to make blood less likely to clot, reducing risk of heart attack and stroke. This could be the reason that alcohol seems to produce health benefits when consumed in moderate amounts.^[88] Also, alcohol dilates blood vessels. Consequently, a person will feel warmer, and his/her skin flush and appear pink.^[52]

7.2.3 Magnitude of effects

Some individuals have less effective forms of one or both of the metabolizing enzymes, and can experience more severe symptoms from ethanol consumption than others. However, those having acquired **alcohol tolerance** have a greater quantity of these enzymes, and metabolize ethanol more rapidly.^[89]

8 Physical and chemical properties

Further information: **Ethanol** (data page)

8.1 Physical properties

Ethanol is a volatile, colorless liquid that has a slight odor. It burns with a smokeless blue flame that is not always visible in normal light.

The physical properties of ethanol stem primarily from the presence of its **hydroxyl** group and the shortness of its carbon chain. Ethanol's hydroxyl group is able to participate in hydrogen bonding, rendering it more viscous and less volatile than less polar organic compounds of similar molecular weight, such as **propane**.

Ethanol is slightly more refractive than water, having a refractive index of 1.36242 (at $\lambda=589.3$ nm and 18.35 °C or 65.03 °F).^[90]



Ethanol burning with its spectrum depicted

The triple point for ethanol is 150 K at a pressure of 4.3×10^{-4} Pa.^[91]

8.2 Solvent properties

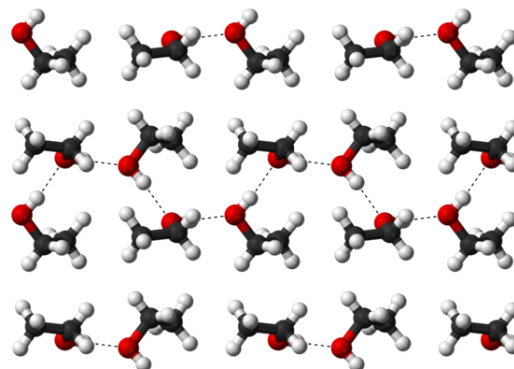
Ethanol is a versatile solvent, miscible with water and with many organic solvents, including acetic acid, acetone, benzene, carbon tetrachloride, chloroform, diethyl ether, ethylene glycol, glycerol, nitromethane, pyridine, and toluene.^{[90][92]} It is also miscible with light aliphatic hydrocarbons, such as pentane and hexane, and with aliphatic chlorides such as trichloroethane and tetrachloroethylene.^[92]

Ethanol's miscibility with water contrasts with the immiscibility of longer-chain alcohols (five or more carbon atoms), whose water miscibility decreases sharply as the number of carbons increases.^[93] The miscibility of ethanol with alkanes is limited to alkanes up to undecane: mixtures with dodecane and higher alkanes show a miscibility gap below a certain temperature (about 13 °C for dodecane^[94]). The miscibility gap tends to get wider with higher alkanes and the temperature for complete miscibility increases.

Ethanol-water mixtures have less volume than the sum of their individual components at the given fractions. Mixing equal volumes of ethanol and water results in only

1.92 volumes of mixture.^{[90][95]} Mixing ethanol and water is exothermic, with up to 777 J/mol^[96] being released at 298 K.

Mixtures of ethanol and water form an azeotrope at about 89 mole-% ethanol and 11 mole-% water^[97] or a mixture of 95.6 percent ethanol by mass (or about 97% alcohol by volume) at normal pressure, which boils at 351K (78 °C). This azeotropic composition is strongly temperature- and pressure-dependent and vanishes at temperatures below 303 K.^[98]



Hydrogen bonding in solid ethanol at -186 °C

Hydrogen bonding causes pure ethanol to be hygroscopic to the extent that it readily absorbs water from the air. The polar nature of the hydroxyl group causes ethanol to dissolve many ionic compounds, notably sodium and potassium hydroxides, magnesium chloride, calcium chloride, ammonium chloride, ammonium bromide, and sodium bromide.^[92] Sodium and potassium chlorides are slightly soluble in ethanol.^[92] Because the ethanol molecule also has a nonpolar end, it will also dissolve nonpolar substances, including most essential oils^[99] and numerous flavoring, coloring, and medicinal agents.

The addition of even a few percent of ethanol to water sharply reduces the surface tension of water. This property partially explains the "tears of wine" phenomenon. When wine is swirled in a glass, ethanol evaporates quickly from the thin film of wine on the wall of the glass. As the wine's ethanol content decreases, its surface tension increases and the thin film "beads up" and runs down the glass in channels rather than as a smooth sheet.

8.3 Flammability

An ethanol-water solution that contains 40% alcohol by weight will catch fire if heated to about 26 °C (79 °F) and if an ignition source is applied to it. This is called its flash point.^[100] The flash point of pure ethanol is 16.60 °C (61.88 °F), less than average room temperature.

Alcoholic beverages that have a low concentration of ethanol will burn if sufficiently heated and an ignition

source (such as an electric spark or a match) is applied to them. For example, the flash point of ordinary wine containing 12.5% ethanol is about 52 °C (126 °F).^[102]

Dishes using burning alcohol for culinary effects are called *Flambé*.

9 Natural occurrence

Ethanol is a byproduct of the metabolic process of yeast. As such, ethanol will be present in any yeast habitat. Ethanol can commonly be found in overripe fruit.^[103] Ethanol produced by symbiotic yeast can be found in Bertam Palm blossoms. Although some animal species such as the Pentailed Treeshrew exhibit ethanol-seeking behaviors, most show no interest or avoidance of food sources containing ethanol.^[104] Ethanol is also produced during the germination of many plants as a result of natural anerobiosis.^[105] Ethanol has been detected in outer space, forming an icy coating around dust grains in interstellar clouds.^[106] Minute quantity amounts (average 196 ppb) of endogenous ethanol and acetaldehyde were found in the exhaled breath of healthy volunteers.^[107] Auto-brewery syndrome, also known as gut fermentation syndrome, is a rare medical condition in which intoxicating quantities of ethanol are produced through endogenous fermentation within the digestive system.^[108]



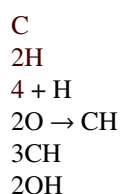
94% denatured ethanol sold in a bottle for household use

10 Production

Ethanol is produced both as a petrochemical, through the hydration of ethylene and, via biological processes, by fermenting sugars with yeast.^[109] Which process is more economical depends on prevailing prices of petroleum and grain feed stocks.

10.1 Ethylene hydration

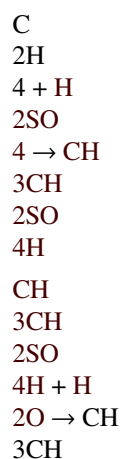
Ethanol for use as an industrial feedstock or solvent (sometimes referred to as synthetic ethanol) is made from petrochemical feed stocks, primarily by the acid-catalyzed hydration of ethylene:

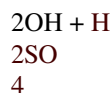


The catalyst is most commonly phosphoric acid,^{[110][111]} adsorbed onto a porous support such as silica gel or diatomaceous earth. This catalyst was first used for large-scale ethanol production by the Shell Oil Company in 1947.^[112] The reaction is carried out in the presence of

high pressure steam at 300 °C (572 °F) where a 1.0:0.6 ethylene to steam ratio is maintained.^{[113][114]} In the U.S., this process was used on an industrial scale by Union Carbide Corporation and others, but now only LyondellBasell uses it commercially.

In an older process, first practiced on the industrial scale in 1930 by Union Carbide,^[115] but now almost entirely obsolete, ethylene was hydrated indirectly by reacting it with concentrated sulfuric acid to produce ethyl sulfate, which was hydrolyzed to yield ethanol and regenerate the sulfuric acid.^[116]



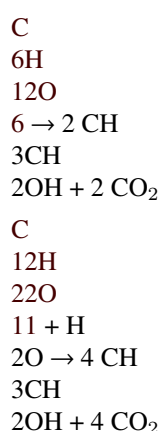


10.2 Fermentation

Main article: Ethanol fermentation

See also: Yeast in winemaking

Ethanol in alcoholic beverages and fuel is produced by fermentation. Certain species of yeast (e.g., *Saccharomyces cerevisiae*) metabolizes sugar producing ethanol and carbon dioxide. The chemical equations below summarize the conversion:



Fermentation is the process of culturing yeast under favorable thermal conditions to produce alcohol. This process is carried out at around 35–40 °C (95–104 °F). Toxicity of ethanol to yeast limits the ethanol concentration obtainable by brewing; higher concentrations, therefore, are obtained by fortification or distillation. The most ethanol-tolerant yeast strains can survive up to approximately 18% ethanol by volume.

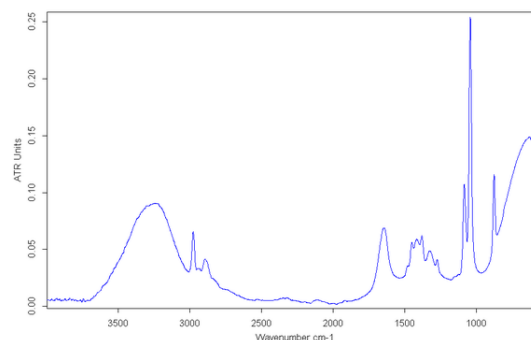
To produce ethanol from starchy materials such as cereal grains, the starch must first be converted into sugars. In brewing beer, this has traditionally been accomplished by allowing the grain to germinate, or malt, which produces the enzyme amylase. When the malted grain is mashed, the amylase converts the remaining starches into sugars.

10.2.1 Cellulose

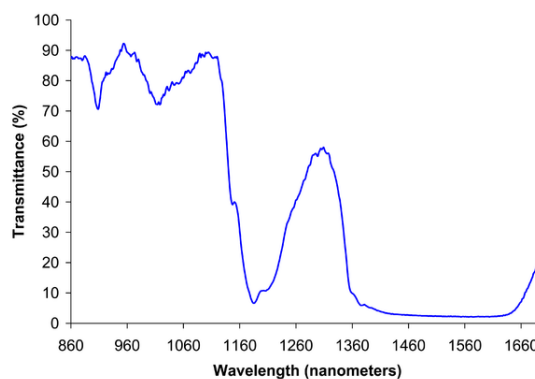
Main article: Cellulosic ethanol

Sugars for ethanol fermentation can be obtained from cellulose. Deployment of this technology could turn a number of cellulose-containing agricultural by-products, such as corncobs, straw, and sawdust, into renewable energy resources. Other agricultural residues such as sugar cane bagasse and energy crops such as switchgrass may also be a sources of fermentable sugars.^[117]

10.3 Testing



Infrared reflection spectra of liquid ethanol, showing the -OH band centered at $\sim 3300 \text{ cm}^{-1}$ and C-H bands at $\sim 2950 \text{ cm}^{-1}$.



Near infrared spectrum of liquid ethanol.

Breweries and biofuel plants employ two methods for measuring ethanol concentration. Infrared ethanol sensors measure the vibrational frequency of dissolved ethanol using the CH band at 2900 cm^{-1} . This method uses a relatively inexpensive solid state sensor that compares the CH band with a reference band to calculate the ethanol content. The calculation makes use of the Beer-Lambert law. Alternatively, by measuring the density of the starting material and the density of the product, using a hydrometer, the change in specific gravity during fermentation indicates the alcohol content. This inexpensive and indirect method has a long history in the beer brewing industry.

11 Purification

11.1 Distillation

Ethylene hydration or brewing produces an ethanol–water mixture. For most industrial and fuel uses, the ethanol must be purified. Fractional distillation can concentrate ethanol to 95.6% by volume (89.5 mole%). This mixture is an azeotrope with a boiling point of 78.1 °C (172.6

°F), and *cannot* be further purified by distillation. Addition of an entraining agent, such as **benzene**, **cyclohexane**, or **heptane**, allows a new ternary azeotrope comprising the ethanol, water, and the entraining agent to be formed. This lower-boiling ternary azeotrope is removed preferentially, leading to water-free ethanol.^[111]

At pressures less than atmospheric pressure, the composition of the ethanol-water azeotrope shifts to more ethanol-rich mixtures, and at pressures less than 70 torr (9.333 kPa), there is no azeotrope, and it is possible to distill absolute ethanol from an ethanol-water mixture. While vacuum distillation of ethanol is not presently economical, pressure-swing distillation is a topic of current research. In this technique, a reduced-pressure distillation first yields an ethanol-water mixture of more than 95.6% ethanol. Then, fractional distillation of this mixture at atmospheric pressure distills off the 95.6% azeotrope, leaving anhydrous ethanol at the bottom.

11.2 Molecular sieves and desiccants

Apart from distillation, ethanol may be dried by addition of a desiccant, such as **molecular sieves**, **cellulose**, and **cornmeal**. The desiccants can be dried and reused.^[111]

Molecular sieves can be used to selectively absorb the water from the 95.6% ethanol solution. Synthetic **zeolite** in pellet form can be used, as well as a variety of plant-derived absorbents, including **cornmeal**, **straw**, and **sawdust**. The zeolite bed can be regenerated essentially an unlimited number of times by drying it with a blast of hot **carbon dioxide**. Cornmeal and other plant-derived absorbents cannot readily be regenerated, but where ethanol is made from grain, they are often available at low cost. Absolute ethanol produced this way has no residual benzene, and can be used to fortify port and sherry in traditional winery operations.

11.3 Membranes and reverse osmosis

Membranes can also be used to separate ethanol and water. Membrane-based separations are not subject to the limitations of the water-ethanol azeotrope because the separations are not based on vapor-liquid equilibria. Membranes are often used in the so-called hybrid membrane distillation process. This process uses a pre-concentration distillation column as first separating step. The further separation is then accomplished with a membrane operated either in vapor permeation or pervaporation mode. Vapor permeation uses a vapor membrane feed and pervaporation uses a liquid membrane feed.

11.4 Other techniques

A variety of other techniques have been discussed, including the following.^[111]

- **Liquid-liquid extraction** of ethanol from an aqueous solution;
- Extraction of ethanol from grain mash by **supercritical carbon dioxide**;
- **Pervaporation**;
- **Fractional freezing** is also used to concentrate fermented alcoholic solutions, such as traditionally made **Applejack** (beverage);
- **Pressure swing adsorption**.^[118]

11.5 Grades of ethanol

11.5.1 Denatured alcohol

Main article: **Denatured alcohol**

Pure ethanol and alcoholic beverages are heavily **taxed** as psychoactive drugs, but ethanol has many uses that do not involve consumption by humans. To relieve the tax burden on these uses, most jurisdictions waive the tax when an agent has been added to the ethanol to render it unfit to drink. These include **bittering agents** such as **denatonium benzoate** and toxins such as **methanol**, **naphtha**, and **pyridine**. Products of this kind are called *denatured alcohol*.^{[119][120]}

11.5.2 Absolute alcohol

Absolute or anhydrous alcohol refers to ethanol with a low water content. There are various grades with maximum water contents ranging from 1% to a few parts per million (ppm) levels. If **azeotropic distillation** is used to remove water, it will contain trace amounts of the material separation agent (e.g. **benzene**).^[121] Absolute alcohol is not intended for human consumption. Absolute ethanol is used as a solvent for laboratory and industrial applications, where water will react with other chemicals, and as fuel alcohol. Spectroscopic ethanol is an absolute ethanol with a low absorbance in ultraviolet and visible light, fit for use as a solvent in ultraviolet-visible spectroscopy.^[122]

Pure ethanol is classed as 200 proof in the U.S., equivalent to 175 degrees proof in the UK system.^[123]

11.5.3 Rectified spirits

Rectified spirit, an azeotropic composition of 96% ethanol containing 4% water, is used instead of anhydrous ethanol for various purposes. Wine spirits are about 94% ethanol (188 proof). The impurities are different from those in 95% (190 proof) laboratory ethanol.^[124]

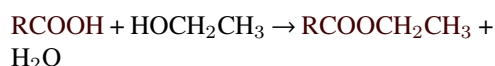
12 Reactions

For more details on this topic, see Alcohol.

Ethanol is classified as a primary alcohol, meaning that the carbon its hydroxyl group attaches to has at least two hydrogen atoms attached to it as well. Many ethanol reactions occur at its hydroxyl group.

12.1 Ester formation

In the presence of acid catalysts, ethanol reacts with carboxylic acids to produce ethyl esters and water:



This reaction, which is conducted on large scale industrially, requires the removal of the water from the reaction mixture as it is formed. Esters react in the presence of an acid or base to give back the alcohol and a salt. This reaction is known as saponification because it is used in the preparation of soap. Ethanol can also form esters with inorganic acids. Diethyl sulfate and triethyl phosphate are prepared by treating ethanol with sulfur trioxide and phosphorus pentoxide respectively. Diethyl sulfate is a useful ethylating agent in organic synthesis. Ethyl nitrite, prepared from the reaction of ethanol with sodium nitrite and sulfuric acid, was formerly used as a diuretic.

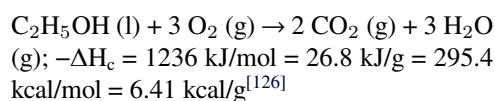
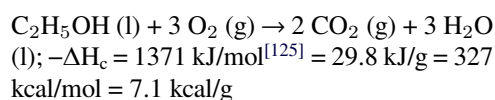
12.2 Dehydration

Strong acid desiccants cause the partial dehydration of ethanol to form diethyl ether and other byproducts. If the dehydration temperature exceeds around 160 °C (320 °F), full dehydration will occur and ethylene will be the main product.



12.3 Combustion

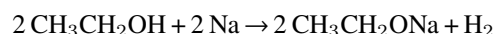
Complete combustion of ethanol forms carbon dioxide and water:



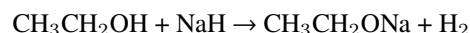
Specific heat = 2.44 kJ/(kg·K)

12.4 Acid-base chemistry

Ethanol is a neutral molecule and the pH of a solution of ethanol in water is nearly 7.00. Ethanol can be quantitatively converted to its conjugate base, the ethoxide ion ($\text{CH}_3\text{CH}_2\text{O}^-$), by reaction with an alkali metal such as sodium:^[93]



or a very strong base such as sodium hydride:

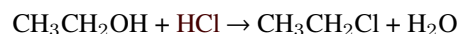


The acidity of water and ethanol are nearly the same, as indicated by their pKa of 15.7 and 16 respectively. Thus, sodium ethoxide and sodium hydroxide exist in an equilibrium that is closely balanced:

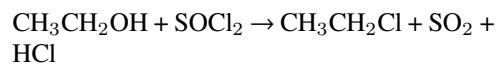


12.5 Halogenation

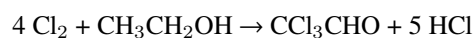
Ethanol is not used industrially as a precursor to ethyl halides, but the reactions are illustrative. Ethanol reacts with hydrogen halides to produce ethyl halides such as ethyl chloride and ethyl bromide via an SN2 reaction:



These reactions require a catalyst such as zinc chloride.^[116] HBr requires refluxing with a sulfuric acid catalyst.^[116] Ethyl halides can, in principle, also be produced by treating ethanol with more specialized halogenating agents, such as thionyl chloride or phosphorus tribromide.^{[93][116]}



Upon treatment with halogens in the presence of base, ethanol gives the corresponding haloform (CHX_3 , where X = Cl, Br, I). This conversion is called the haloform reaction.^[127] An intermediate in the reaction with chlorine is the aldehyde called chloral:



12.6 Oxidation

Ethanol can be oxidized to acetaldehyde and further oxidized to acetic acid, depending on the reagents and

conditions.^[116] This oxidation is of no importance industrially, but in the human body, these oxidation reactions are catalyzed by the enzyme **liver alcohol dehydrogenase**. The oxidation product of ethanol, acetic acid, is a nutrient for humans, being a precursor to **acetyl CoA**, where the acetyl group can be spent as energy or used for biosynthesis.

13 History

For more details on this topic, see **Distilled beverage**.

The fermentation of sugar into ethanol is one of the earliest **biotechnologies** employed by humans. The intoxicating effects of ethanol consumption have been known since ancient times. Ethanol has been used by humans since prehistory as the intoxicating ingredient of **alcoholic beverages**. Dried residue on 9,000-year-old pottery found in China suggests that **Neolithic** people consumed alcoholic beverages.^[128]

Although distillation was well known by the early Greeks and Arabs, the first recorded production of alcohol from distilled wine was by the **School of Salerno** alchemists in the 12th century.^[129] The first to mention absolute alcohol, in contrast with alcohol-water mixtures, was **Raymond Lull**.^[129]

In 1796, German-Russian chemist **Johann Tobias Lowitz** obtained pure ethanol by mixing partially purified ethanol (the alcohol-water azeotrope) with an excess of anhydrous alkali and then distilling the mixture over low heat.^[130] French chemist **Antoine Lavoisier** described ethanol as a compound of carbon, hydrogen, and oxygen, and in 1807 **Nicolas-Théodore de Saussure** determined ethanol's chemical formula.^{[131][132]} Fifty years later, **Archibald Scott Couper** published the structural formula of ethanol. It was one of the first structural formulas determined.^[133]

Ethanol was first prepared synthetically in 1825 by **Michael Faraday**. He found that sulfuric acid could absorb large volumes of coal gas.^[134] He gave the resulting solution to **Henry Hennell**, a British chemist, who found in 1826 that it contained "sulphovinic acid" (ethyl hydrogen sulfate).^[135] In 1828, Hennell and the French chemist **Georges-Simon Sérullas** independently discovered that sulphovinic acid could be decomposed into ethanol.^{[136][137]} Thus, in 1825 Faraday had unwittingly discovered that ethanol could be produced from **ethylene** (a component of coal gas) by acid-catalyzed hydration, a process similar to current industrial ethanol synthesis.^[138]

Ethanol was used as lamp fuel in the United States as early as 1840, but a tax levied on industrial alcohol during the **Civil War** made this use uneconomical. The tax was repealed in 1906.^[139] Use as an automotive fuel dates back to 1908, with the **Ford Model T** able to run on petrol (gasoline) or ethanol.^[140] It fuels some spirit lamps.

Ethanol intended for industrial use is often produced from **ethylene**.^[141] Ethanol has widespread use as a solvent of substances intended for human contact or consumption, including scents, flavorings, colorings, and medicines. In chemistry, it is both a solvent and a feedstock for the synthesis of other products. It has a long history as a fuel for heat and light, and more recently as a fuel for **internal combustion engines**.

14 Society and culture

For more details on this topic, see **Drinking culture**.

A 2002 study found 41% of people fatally injured in traffic accidents were in alcohol related crashes.^[142] The risk of a fatal car accident increases exponentially with the level of alcohol in the driver's blood.^[143] Most drunk driving laws governing the acceptable levels in the blood while driving or operating heavy machinery set typical upper limits of legal blood alcohol content (BAC) at 0.08%.^[144]

15 See also

- **1-Propanol**
- **2,2,2-Trichloroethanol**
- **Breathalyzer**
- **Butanol fuel**
- **Ethanol (data page)**
- **Cellulosic ethanol commercialization**
- **Ethenol**
- **Ethynol**
- **Isopropyl alcohol**
- **Rubbing alcohol**
- **Timeline of alcohol fuel**
- **Ethanol induced non-lamellar phases in phospholipids**

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- ΔFosB as a therapeutic biomarker
- The strong correlation between chronic drug exposure and ΔFosB provides novel opportunities for targeted therapies in addiction (118), and suggests methods to analyze their efficacy (119). Over the past two decades, research has progressed from identifying ΔFosB induction to investigating its subsequent action (38). It is likely that ΔFosB research will now progress into a new era – the use of ΔFosB as a biomarker. If ΔFosB detection is indicative of chronic drug exposure (and is at least partly responsible for dependence of the substance), then its monitoring for therapeutic efficacy in interventional studies is a suitable biomarker (Figure 2). Examples of therapeutic avenues are discussed herein. ...
- Conclusions
- ΔFosB is an essential transcription factor implicated in the molecular and behavioral pathways of addiction following repeated drug exposure. The formation of ΔFosB in multiple brain regions, and the molecular pathway leading to the formation of AP-1 complexes is well understood. The establishment of a functional purpose for ΔFosB has allowed further determination as to some of the key aspects of its molecular cascades, involving effectors such as GluR2 (87,88), Cdk5 (93) and NFκB (100). Moreover, many of these molecular changes identified are now directly linked to the structural, physiological and behavioral changes observed following chronic drug exposure (60,95,97,102). New frontiers of research investigating the molecular roles of ΔFosB have been opened by epigenetic studies, and recent advances have illustrated the role of ΔFosB acting on DNA and histones, truly as a "molecular switch" (34). As a consequence of our improved understanding of ΔFosB in addiction, it is possible to evaluate the addictive potential of current medications (119), as well as use it as a biomarker for assessing the efficacy of therapeutic interventions (121,122,124). Some of these proposed interventions have limitations (125) or are in their infancy (75). However, it is hoped that some of these preliminary findings may lead to innovative treatments, which are much needed in addiction.
- [66] Nestler EJ (December 2013). "Cellular basis of memory for addiction". *Dialogues Clin Neurosci* **15** (4): 431–443. PMC 3898681. PMID 24459410. Despite the Importance of Numerous Psychosocial Factors, at its Core, Drug Addiction Involves a Biological Process: the ability of repeated exposure to a drug of abuse to induce changes in a vulnerable brain that drive the compulsive seeking and taking of drugs, and loss of control over drug use, that define a state of addiction. ... A large body of literature has demonstrated that such ΔFosB induction in D1-type NAc neurons increases an animal's sensitivity to drug as well as natural rewards and promotes drug self-administration, presumably through a process of positive reinforcement
- [67] Robison AJ, Nestler EJ (November 2011). "Transcriptional and epigenetic mechanisms of addiction". *Nat. Rev. Neurosci.* **12** (11): 623–637. doi:10.1038/nrn3111. PMC 3272277. PMID 21989194. ΔFosB has been linked directly to several addiction-

- related behaviors ... Importantly, genetic or viral overexpression of Δ JunD, a dominant negative mutant of JunD which antagonizes Δ FosB- and other AP-1-mediated transcriptional activity, in the NAc or OFC blocks these key effects of drug exposure^{14,22–24}. This indicates that Δ FosB is both necessary and sufficient for many of the changes wrought in the brain by chronic drug exposure. Δ FosB is also induced in D1-type NAc MSNs by chronic consumption of several natural rewards, including sucrose, high fat food, sex, wheel running, where it promotes that consumption^{14,26–30}. This implicates Δ FosB in the regulation of natural rewards under normal conditions and perhaps during pathological addictive-like states. ... Δ FosB serves as one of the master control proteins governing this structural plasticity.
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17 Further reading

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18 External links

- Alcohol (Ethanol) at *The Periodic Table of Videos* (University of Nottingham)
- International Labour Organization ethanol safety information
- National Pollutant Inventory – Ethanol Fact Sheet
- CDC – NIOSH Pocket Guide to Chemical Hazards – Ethyl Alcohol
- National Institute of Standards and Technology chemical data on ethanol
- ChEBI – biology related
- Chicago Board of Trade news and market data on ethanol futures
- Calculation of vapor pressure, liquid density, dynamic liquid viscosity, surface tension of ethanol
- Ethanol History A look into the history of ethanol
- ChemSub Online: Ethyl alcohol
- Industrial ethanol production process flow diagram using ethylene and sulphuric acid

Pharmacology of ethanol

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19.1 Text

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