Hydrochloric acid

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IUPAC name	Hydrochloric acid
Other names	Muriatic acid, Spirit of salt
Identifiers	
CAS number	7647-01-0
RTECS number	MW4025000
Properties	
Molecular formula	HCl

Molar mass	36.46 g/mol
Appearance	Clear colorless to light-yellow liquid
Melting point	−26 °C (38% solution)
Boiling point	110 °C (20.2% solution); 48 °C (38% solution)
Solubility in water	Fully miscible.
Viscosity	1.9 mPa·s at 25 °C, 31.5% solution
Hazards	
MSDS	External MSDS
MSDS	External MSDS
R-phrases	R34, R37, S26, S36, S45
Flash point	Non-flammable.
Supplementary data page	
Structure and properties	*n*, ε_r, etc.
Thermodynamic data	Phase behaviour Solid, liquid, gas
Spectral data	UV, IR, NMR, MS
Except where noted otherwise, data are given for materials in their standard state (at 25 °C, 100 kPa) Infobox disclaimer and references	

The chemical compound **hydrochloric acid** is the aqueous (water-based) solution of hydrogen chloride gas (HCl). It is a strong acid, the major component of gastric acid and of wide industrial use. Hydrochloric acid must be handled with appropriate safety precautions because it is a highly corrosive liquid.

Hydrochloric acid, or **muriatic acid** by its historical but still occasionally used name, has been an important and frequently used chemical from early history and was discovered by the alchemist Jabir ibn Hayyan around the year 800. It was used throughout the

Middle Ages by alchemists in the quest for the philosopher's stone, and later by several European scientists including Glauber, Priestley, and Davy, to help establish modern chemical knowledge.

From the Industrial Revolution, it became an important industrial chemical for many applications, including the large-scale production of organic compounds, such as vinyl chloride for PVC plastic, and MDI/TDI for polyurethane, and smaller-scale applications, such as production of gelatin and other ingredients in food, and leather processing. About 20 million metric tonnes of HCl gas are produced annually.

Contents

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[edit] History

Hydrochloric acid was first discovered around 800 AD by the alchemist Jabir ibn Hayyan (Geber), by mixing common salt with vitriol (sulfuric acid). Jabir discovered many important chemicals, and recorded his findings in over twenty books, which carried his chemical knowledge of hydrochloric acid and other basic chemicals for hundreds of years. Jabir's invention of the gold-dissolving aqua regia, consisting of hydrochloric acid and nitric acid, was of great interest to alchemists searching for the philosopher's stone.

Jabir ibn Hayyan, medieval manuscript drawing

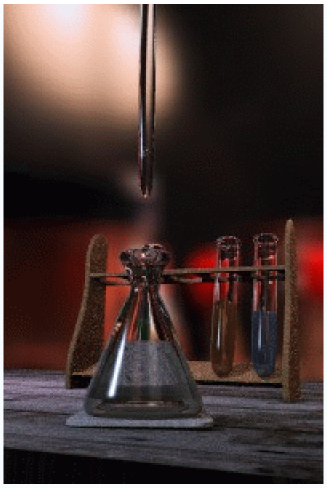
In the Middle Ages, hydrochloric acid was known to European alchemists as *spirit of salt* or *acidum salis*. Gaseous HCl was called *marine acid air*. The old (pre-systematic) name *muriatic acid* has the same origin (*muriatic* means "pertaining to brine or salt"), and this name is still sometimes used. Notable production was recorded by Basilius Valentinus, the alchemist-canon of the Benedictine priory Sankt Peter in Erfurt, Germany in the fifteenth century. In the seventeenth century, Johann Rudolf Glauber from Karlstadt am Main, Germany used sodium chloride salt and sulfuric acid for the preparation of sodium sulfate in the Mannheim process, releasing hydrogen chloride gas. Joseph Priestley of Leeds, England prepared pure hydrogen chloride in 1772, and in 1818 Humphry Davy of Penzance, England proved that the chemical composition included hydrogen and chlorine.

During the Industrial Revolution in Europe, demand for alkaline substances such as soda ash increased, and the new industrial soda process by Nicolas Leblanc (Issoundun, France) enabled cheap large-scale production. In the Leblanc process, salt is converted to soda ash, using sulfuric acid, limestone, and coal, releasing hydrogen chloride as a by-product. Until the Alkali Act of 1863, excess HCl was vented to the air. After the passage of the act, soda ash producers were obliged to absorb the waste gas in water, producing hydrochloric acid on an industrial scale.

When early in the twentieth century the Leblanc process was effectively replaced by the Solvay process without the hydrochloric acid by-product, hydrochloric acid was already fully settled as an important chemical in numerous applications. The commercial interest initiated other production methods which are still used today, as described below. Today, most hydrochloric acid is made by absorbing hydrogen chloride from industrial organic compounds production.

Hydrochloric acid is listed as a Table II precursor under the 1988 Convention Against Illicit Traffic in Narcotic Drugs and Psychotropic Substances because of its use in the production of heroin, cocaine, and methamphetamine.[1]

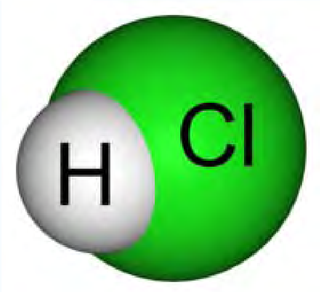
[edit] Chemistry



Acid titration

Hydrogen chloride (HCl) is a monoprotic acid, which means it can dissociate (*i.e.*, ionize) only once to give up one H^+ ion (a single proton). In aqueous hydrochloric acid, the H^+ joins a water molecule to form a hydronium ion, H_3O^+:

$$HCl + H_2O \rightleftharpoons H_3O^+ + Cl^-$$



Molecular model of hydrogen chloride.

The other ion formed is Cl^-, the chloride ion. Hydrochloric acid can therefore be used to prepare salts called *chlorides,* such as sodium chloride. Hydrochloric acid is a strong acid, since it is fully dissociated in water.

Monoprotic acids have one acid dissociation constant, K_a, which indicates the level of dissociation in water. For a strong acid like HCl, the K_a is large. Theoretical attempts to assign a K_a to HCl have been made.[2] When chloride salts such as NaCl are added to aqueous HCl they have practically no effect on pH, indicating that Cl^- is an exceedingly weak conjugate base and that HCl is fully dissociated in aqueous solution. For intermediate to strong solutions of hydrochloric acid, the assumption that H^+ molarity (a unit of concentration) equals HCl molarity is excellent, agreeing to four significant digits.

Of the seven common strong acids in chemistry, all of them inorganic, hydrochloric acid is the monoprotic acid least likely to undergo an interfering oxidation-reduction reaction. It is one of the least hazardous strong acids to handle; despite its acidity, it produces the less reactive and non-toxic chloride ion. Intermediate strength hydrochloric acid solutions are quite stable, maintaining their concentrations over time. These attributes, plus the fact that it is available as a pure reagent, mean that hydrochloric acid makes an excellent acidifying reagent and acid titrant (for determining the amount of an unknown quantity of base in titration). Strong acid titrants are useful because they give more distinct endpoints in a titration, making the titration more precise. Hydrochloric acid is frequently used in chemical analysis and to digest samples for analysis. Concentrated hydrochloric acid will dissolve some metals to form oxidized metal chlorides and hydrogen gas. It will produce metal chlorides from basic compounds such as calcium carbonate or copper(II) oxide. It is also used as a simple acid catalyst for some chemical reactions.

[edit] Physical properties

The physical properties of hydrochloric acid, such as boiling and melting points, density, and pH depend on the concentration or molarity of HCl in the acid solution. They can range from those of water at 0% HCl to values for fuming hydrochloric acid at over 40% HCl.

Conc. (w/w) c : kg HCl/kg	**Conc. (w/v)** c : kg HCl/m^3	**Conc. Baumé**	**Density** ρ : kg/l	**Molarity** M	**pH**	**Viscosity** η : mPa·s	**Specific heat** s : kJ/(kg·K)	**Vapor pressure** P_{HCl} : Pa	**Boiling point** b.p.	**Melting point** m.p.
10%	104.80	6.6	1.048	2.87 M	-0.5	1.16	3.47	0.527	103 °C	-18 °C
20%	219.60	13	1.098	6.02 M	-0.8	1.37	2.99	27.3	108 °C	-59 °C
30%	344.70	19	1.149	9.45 M	-1.0	1.70	2.60	1,410	90 °C	-52 °C
32%	370.88	20	1.159	10.17 M	-1.0	1.80	2.55	3,130	84 °C	-43 °C
34%	397.46	21	1.169	10.90 M	-1.0	1.90	2.50	6,733	71 °C	-36 °C
36%	424.44	22	1.179	11.64 M	-1.1	1.99	2.46	14,100	61 °C	-30 °C
38%	451.82	23	1.189	12.39 M	-1.1	2.10	2.43	28,000	48 °C	-26 °C

The reference temperature and pressure for the above table are 20 °C and 1 atmosphere (101 kPa).

Hydrochloric acid as the binary (two-component) mixture of HCl and H_2O has a constant-boiling azeotrope at 20.2% HCl and 108.6 °C (227 °F). There are four constant-crystallization eutectic points for hydrochloric acid, between the crystal form of $HCl·H_2O$ (68% HCl), $HCl·2H_2O$ (51% HCl), $HCl·3H_2O$ (41% HCl), $HCl·6H_2O$ (25% HCl), and ice

(0% HCl). There is also a metastable eutectic point at 24.8% between ice and the $HCl \cdot 3H_2O$ crystallization

[edit] Production

Main article: hydrogen chloride

Hydrochloric acid is prepared by dissolving hydrogen chloride in water. Hydrogen chloride can be generated in many ways, and thus several different precursors to hydrochloric acid exist. The large scale production of hydrochloric acid is almost always integrated with other industrial scale chemicals production.

[edit] Industrial market

Hydrochloric acid is produced in solutions up to 38% HCl (concentrated grade). Higher concentrations up to just over 40% are chemically possible, but the evaporation rate is then so high that storage and handling need extra precautions, such as pressure and low temperature. Bulk industrial-grade is therefore 30% to 34%, optimized for effective transport and limited product loss by HCl vapors. Solutions for household purposes, mostly cleaning, are typically 10% to 12%, with strong recommendations to dilute before use.

Major producers worldwide include Dow Chemical at 2 million metric tonnes annually (2 Mt/year), calculated as HCl gas, and FMC, Georgia Gulf Corporation, Tosoh Corporation, Akzo Nobel, and Tessenderlo at 0.5 to 1.5 Mt/year each. Total world production, for comparison purposes expressed as HCl, is estimated at 20 Mt/year, with 3 Mt/year from direct synthesis, and the rest as secondary product from organic and similar syntheses. By far, most of all hydrochloric acid is consumed captively by the producer. The open world market size is estimated at 5 Mt/year.

[edit] Applications

Hydrochloric acid is a strong inorganic acid that is used in many industrial processes. The application often determines the required product quality.

[edit] Regeneration of ion exchangers

An important application of high-quality hydrochloric acid is the regeneration of ion exchange resins. Cation exchange is widely used to remove ions such as Na^+ and Ca^{2+} from aqueous solutions, producing demineralized water.

Na^+ is replaced by H_3O^+
Ca^{2+} is replaced by 2 H_3O^+

Ion exchangers and demineralized water are used in all chemical industries, drinking water production, and many food industries.

[edit] pH Control and neutralization

A very common application of hydrochloric acid is to regulate the basicity (pH) of solutions.

$$OH^- + HCl \rightarrow H_2O + Cl^-$$

In industry demanding purity (food, pharmaceutical, drinking water), high-quality hydrochloric acid is used to control the pH of process water streams. In less-demanding industry, technical-quality hydrochloric acid suffices for neutralizing waste streams and swimming pool treatment.

[edit] Pickling of steel

Pickling is an essential step in metal surface treatment, to remove rust or iron oxide scale from iron or steel before subsequent processing, such as extrusion, rolling, galvanizing, and other techniques. Technical-quality HCl at typically 18% concentration is the most commonly-used pickling agent for the pickling of carbon steel grades.

$$Fe_2O_3 + Fe + 6\ HCl \rightarrow 3\ FeCl_2 + 3\ H_2O$$

The spent acid has long been re-used as ferrous chloride solutions, but high heavy-metal levels in the pickling liquor has decreased this practice.

In recent years, the steel pickling industry has however developed hydrochloric acid regeneration processes, such as the spray roaster or the fluidized bed HCl regeneration process, which allow the recovery of HCl from spent pickling liquor. The most common regeneration process is the pyrohydrolysis process, applying the following formula:

$$4\ FeCl_2 + 4\ H_2O + O_2 \rightarrow 8\ HCl + 2\ Fe_2O_3$$

By recuperation of the spent acid, a closed acid loop is established. The ferric oxide by product of the regeneration process is a valuable by-product, used in a variety of secondary industries.

HCl is not a common pickling agent for stainless steel grades.

[edit] Production of inorganic compounds

Numerous products can be produced with hydrochloric acid in normal acid-base reactions, resulting in inorganic compounds. These include water treatment chemicals such as iron(III) chloride and polyaluminium chloride (PAC).

$Fe_2O_3 + 6\ HCl \rightarrow 2\ FeCl_3 + 3\ H_2O$

Both iron(III) chloride and PAC are used as flocculation and coagulation agents in wastewater treatment, drinking water production, and paper production.

Other inorganic compounds produced with hydrochloric acid include road application salt calcium chloride, nickel(II) chloride for electroplating, and zinc chloride for the galvanizing industry and battery production.

[edit] Production of organic compounds

The largest hydrochloric acid consumption is in the production of organic compounds such as vinyl chloride for PVC, and MDI and TDI for polyurethane. This is often captive use, consuming locally-produced hydrochloric acid that never actually reaches the open market. Other organic compounds produced with hydrochloric acid include bisphenol A for polycarbonate, activated carbon, and ascorbic acid, as well as numerous pharmaceutical products.

[edit] Other applications

Hydrochloric acid is a fundamental chemical, and as such it is used for a large number of small-scale applications, such as leather processing, household cleaning, and building construction. In addition, a way of stimulating oil production is by injecting hydrochloric acid into the rock formation of an oil well, dissolving a portion of the rock, and creating a large-pore structure. Oil-well acidizing is a common process in the North Sea oil production industry.

Many chemical reactions involving hydrochloric acid are applied in the production of food, food ingredients, and food additives. Typical products include aspartame, fructose, citric acid, lysine, hydrolyzed (vegetable) protein as food enhancer, and in gelatin production. Food-grade (extra-pure) hydrochloric acid can be applied when needed for the final product.

[edit] Presence in living organisms

[edit] Physiology and pathology

Hydrochloric acid constitutes the majority of gastric acid, the human digestive fluid. In a complex process and at a large energetic burden, it is secreted by parietal cells (also known as oxyntic cells). These cells contain an extensive secretory network (called canaliculi) from which the HCl is secreted into the lumen of the stomach. They are part of the fundic glands (also known as oxyntic glands) in the stomach.

Safety mechanisms that prevent the damage of the epithelium of digestive tract by hydrochloric acid are the following:

- Negative regulators of its release
- A thick mucus layer covering the epithelium
- Sodium bicarbonate secreted by gastric epithelial cells and pancreas
- The structure of epithelium (tight junctions)
- Adequate blood supply
- Prostaglandins (many different effects: they stimulate mucus and bicarbonate secretion, maintain epithelial barrier integrity, enable adequate blood supply, stimulate the healing of the damaged mucous membrane)

When, due to different reasons, these mechanisms fail, heartburn or peptic ulcers can develop. Drugs called proton pump inhibitors prevent the body from making excess acid in the stomach, while antacids neutralize existing acid.

In some instances, the stomach does not produce enough hydrochloric acid. These pathologic states are denoted by the terms hypochlorhydria and achlorhydria. Potentially they can lead to gastroenteritis.

[edit] Chemical weapons

Phosgene ($COCl_2$) was a common chemical warfare agent used in World War I. The main effect of phosgene results from the dissolution of the gas in the mucous membranes deep in the lung, where it is converted by hydrolysis into carbonic acid and the corrosive hydrochloric acid. The latter disrupts the alveolar-capillary membranes so that the lung becomes filled with fluid (pulmonary edema).

Hydrochloric acid is also partly responsible for the harmful or blistering effects of mustard gas. In the presence of water, such as on the moist surface of the eyes or lungs, mustard gas breaks down forming hydrochloric acid.

[edit] Safety

Hydrochloric acid in high concentrations forms acidic mists. Both the mist and the solution have a corrosive effect on human tissue, potentially damaging respiratory organs, eyes, skin and intestines. Upon mixing hydrochloric acid with common oxidizing chemicals, such as bleach ($NaClO$) or permanganate ($KMnO_4$), the toxic gas chlorine is produced. To minimize the risks while working with hydrochloric acid, appropriate precautions should be taken, including wearing rubber or PVC gloves, protective eye goggles, and chemical resistant clothing.

Dangerous goods labels

The hazards of solutions of hydrochloric acid depend on the concentration. The following table lists the EU classification of hydrochloric acid solutions:

Concentration by weight	**Classification**	**R-Phrases**
10%–25%	Irritant (**Xi**)	R36/37/38
>25%	Corrosive (**C**)	R34 R37

The Environmental Protection Agency rates and regulates hydrochloric acid as a toxin.[3]

[edit] See also

- List of chemistry topics
- List of inorganic compounds

Related chemical substances

- Hydrochloride, organic salts of hydrochloric acid
- $HClO$ Hypochlorous acid, and its salt hypochlorite
- $HClO_2$ Chlorous acid, and its salt chlorite
- $HClO_3$ Chloric acid, and its salt chlorate
- $HClO_4$ Perchloric acid, and its salt perchlorate

[edit] References and notes

[edit] Notes

1. ^ List of precursors and chemicals frequently used in the illicit manufacture of narcotic drugs and pychotropic substances under international control (PDF). International Narcotics Control Board.
2. ^ Dissociation constants pKa and pKb. ChemBuddy.com.
3. ^ HCl score card. Environmental Protection Agency. Retrieved on 2007-09-12.

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[edit] External links

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- Density table for hydrochloric acid
- NIST WebBook, general link

General safety information

- EPA Hazard Summary
- NIH Description and Hazard Summary
- Hydrochloric acid MSDS by Jones-Hamilton
- Hydrochloric acid MSDS by Hampton Research
- Hydrochloric acid MSDS by American Bioanalytical
- Hydrochloric acid MSDS by Georgia Institute of Technology
- Hydrochloric acid MSDS by Akzo Nobel

Manufacturer information

- Hydrochloric acid product information of Akzo Nobel
- Hydrochloric acid product information of Tessenderlo
- Hydrochloric acid product information of Solvay
- Dow Chemical
- Chlor-Alkali information of Tosoh
- Hydrochloric acid product information of Bayer MaterialScience in North America

Pollution information

- National Pollutant Inventory - Hydrochloric Acid Fact Sheet

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