

Electrodes & Conditioning

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What is passivation of stainless steel?

Source: <https://www.besttechnologyinc.com/passivation-systems/what-is-passivation/#:~:text=Passivation%20is%20a%20widely%2Dused,with%20air%20and%20cause%20corrosion.>

What is passivation, and how does passivation work? How do I passivate stainless steel parts after machining operations? These are questions commonly asked by machine shops and manufacturers of part materials such as stainless steel, titanium and tantalum.

What is passivation of stainless steel?

Passivation is a widely-used metal finishing process to prevent corrosion. In stainless steel, the passivation process uses nitric acid or citric acid to **remove free iron** from the surface. The chemical treatment leads to a protective oxide layer that is less likely to chemically react with air and cause corrosion. Passivated stainless steel resists rust.

Passivation prevents rust in stainless steel

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What does passivated stainless steel mean?

For manufacturers, the [industry standards](#) ASTM A967 and AMS 2700 represent the most widely used standards for passivating stainless steel. According to ASTM A967, the definition of passivation is:

the chemical treatment of stainless steel with a mild oxidant, such as a nitric acid solution, for the purpose of the removal of free iron or other foreign matter.”

Further, ASTM A380 states that passivation is:

removal of exogenous iron or iron compounds from the surface of a stainless steel by means of a chemical dissolution, most typically by a treatment with an acid solution that will remove the surface contamination but will not significantly affect the stainless steel itself ... for the purpose of enhancing the spontaneous formation of the protective passive film.”

History of Passivation Process

In the mid 1800s, chemist [Christian Friedrich Schönbein](#) discovered the effect of passivation. After dipping iron in concentrated nitric acid, he found that the iron had little or no chemical reactivity compared to iron that did not receive the concentrated nitric acid treatment. His name for that lack of chemical reactivity was the “passive” condition.

As passivation of stainless steel with nitric acid became a widespread practice in the 1900s, environmental and safety issues with nitric acid became more apparent. Research done by the [Adolf Coors brewing company](#) in Germany identified citric acid as an effective alternative. In the 1990s, many manufacturers began to adopt citric acid as a safer and more environmentally friendly alternative to nitric acid.

Today the industry standards for surface passivation offer methods for nitric acid or citric acid, or nitric acid with sodium dichromate. Choice of method often depends on customer requirements. Each method has its own advantages and disadvantages. For details, please see our article [Nitric vs. Citric Acid Passivation](#).

Why passivate stainless steel?

Passivation is a post-fabrication best practice for newly-machined stainless steel parts and components. Benefits include:

- Chemical film barrier against rust
- Extended life of the product
- Removal of contamination from product surface
- Reduced need for maintenance.

How does passivation work?

[Stainless steel](#) is an iron-based alloy, typically composed of iron, nickel and chromium. Stainless steel derives its corrosion-resistant properties from the chromium content. Chromium, when exposed to oxygen (air), forms a thin film of chromium oxide that covers the stainless steel surface and protects the underlying iron from rusting. The purpose of passivation is to augment and optimize formation of the chromium oxide layer.

Immersion of stainless steel in an acid bath dissolves free iron from the surface while leaving the chromium intact. The acid chemically removes the free iron, leaving behind a uniform surface with a higher proportion of chromium than the underlying material.

Upon exposure to oxygen in the air after the acid bath, the stainless steel forms the chromic oxide layer over the next 24 to 48 hours. The higher proportion of chromium at the surface allows for the formation of a thicker, more protective chromium oxide layer. Removal of free iron from the surface removes opportunities for corrosion to start.

The resulting passive layer provides a chemically non-reactive surface that protects against rust.

Passivation Layer on Stainless Steel

Passivation Layer - Microscopic View of Passivating Oxide Layer

When is passivation of stainless steel required?

Passivation is a post-fabrication process that is performed after grinding, welding, cutting and other machining operations that manipulate stainless steel. Under ideal conditions, stainless steel naturally resists corrosion, which might suggest that passivating would be unnecessary.

Under normal, realistic conditions, however, any of the following can inhibit the formation of the oxide film that protects against corrosion:

- foreign material in a manufacturing environment (shop dirt, grinding swarf)
- sulfides added to the stainless steel for improved machinability
- particles of iron from cutting tools embedded in the surface of stainless steel parts.

Such contaminants must be removed down to the surface grain boundaries to restore a uniformly corrosion-resistant surface. The passivation process corrects these issues.

What passivation is NOT

- **Not electrolytic.** Passivation is a chemical treatment and *not an electrolytic process*. Passivation does not depend on electrochemical reactions, unlike electropolishing or anodizing.
- **Not for scale removal.** Passivating is not a method to remove oxide scale from machined parts after heat treating or welding.
- **Not a coat of paint.** Passivating stainless steel *does not change the color* or surface appearance of the metal. Passivating is not necessary for items that will be painted or powder coated.

What is passivation? How does passivation work? Passivated stainless steel parts

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How to passivate stainless steel

Many [passivation specifications](#) (ASTM A967, AMS 2700) exist to instruct on the proper process to passivate stainless steel, titanium and other materials. The following chemical cleaning and passivation procedure phases are common to nearly all the specifications:

1. **Clean** – Remove any contaminants from the surface, such as grease and oils.
2. **Passivate** – Perform chemical treatment via immersion in an acid bath, typically [nitric acid](#) or [citric acid](#).
3. **Test** – Test the newly passivated stainless steel surface to ensure effectiveness of the process steps.

Some stainless steel passivation specifications call for adding sodium dichromate to the nitric acid bath to provide more rapid formation of the oxide layer or passivation film. Sodium dichromate, however, is a highly toxic hexavalent chromium compound. Alternative practices include use of [ultrasonic machines](#) and [citric acid](#) such as CitriSurf® to encourage oxygen formation at the metal

surface while the material is still immersed in the acid bath.

Length of time of immersion in the acid tank is typically 20 – 30 minutes. Temperature specifications for the acid can vary, depending on the grade of stainless steel and the acid chemistry, but typically fall between 120 – 150 °F.

Video: Fully Automated Citric Acid Passivation System

Fully Automated Citric Acid Passivation System

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Process steps for passivating stainless steel parts

Putting together a passivation line requires a process that will both clean and passivate stainless steel. Common process steps for passivating stainless steel are as follows:

1. Alkaline cleaning of the materials to remove all contaminants, oils, and foreign materials. Commonly uses detergent cleaners like sodium hydroxide, Micro-90, or Simple Green.
2. Water rinse – Commonly with DI (Deionized) water or RO (Reverse Osmosis) Water in high-precision industries
3. Nitric acid or citric acid (CitriSurf) immersion bath to fully dissolve any free irons and sulfides and expedite the formation of passive film or oxide layer
4. Water rinse – Commonly with DI water in high-precision industries
5. Second water rinse – Commonly with DI Water in high-precision industries
6. Dry parts
7. Test sample parts via specification standards using: salt spray, high humidity chamber exposure, or copper sulfate testing.

What to watch for with passivation of metals

Passivation can be thought of as controlled corrosion. The acid bath dissolves, or corrodes, free iron at the surface in a uniform, controlled manner. When not controlled properly, runaway corrosion can occur in a phenomenon known as “flash attack.” In flash attack, the metal develops a dark, heavily etched surface – exactly the corrosion that the passive layer is intended to prevent.

Keeping the acid solution free of contaminants is critical for preventing flash attack. Often the remedy is as simple as refilling the acid bath with fresh solution. Replacing the acid solution on a regular schedule is recommended to prevent build-up of contaminants in the solution. Use of a higher grade of water (RO water or DI water) with fewer chlorides than tap water may also resolve issues with flash attack.

Thorough cleaning of stainless steel parts BEFORE the acid bath is also crucial. Any grease or cutting oil left on the parts tends to form bubbles that interfere with the process. In these cases, consider using a [degreaser](#) or changing detergents to ensure that the part is completely free of contaminants. In some cases thermal oxides from heat treating or welding may require grinding or pickling for removal before passivating.

Avoid mixing grades of stainless steel (e.g. 300 series and 400 series) in the acid bath at the same time, as this risks galvanic corrosion. In this situation, the less noble metal corrodes faster than it would have if the dissimilar metals had not been in contact in the solution.

What passivation equipment do I need?

Best Technology is recognized as an industry leader in [passivation equipment](#), tanks, systems and lines. Our experts understand the careful balance of chemistry, temperature and immersion time to meet passivation specifications and to avoid costly errors. We offer a broad range of equipment from [tabletop machines](#) to [integrated wet benches](#) to [fully automated systems](#). Our application engineers can design equipment to meet your requirements and specifications.

As you gather information on starting a new passivation line, be sure to check out our [passivation process checklist](#). When you're ready, [contact us](#) to talk with our passivation process experts.

Types of passivation equipment

Passivation equipment is available in a variety of tank sizes. The smallest systems start with a tank size of 1.25 gallon, while the largest systems run to 500+ gallons. A passivation system offers the integrated convenience of facilitating multiple process steps (e.g., wash, rinse, passivate, rinse and dry) in a single unified piece of equipment.

Types of systems include:

- [Small benchtop passivation equipment](#)
- [Wet bench passivation equipment](#)
- [Automated passivation systems](#)
- [Agitated immersion passivation systems](#)

Click any of the following images to learn more about that type of equipment.

Small Benchtop Passivation Equipment

Small Tabletop Stainless Steel Parts Passivation Equipment

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Wet Bench Passivation Equipment

Ultrasonic Cleaning Passivation Console

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Automated Passivation Systems

Ultrasonic Automated Passivation Equipment

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Agitated Immersion Passivation Systems

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Passivation standards and specifications

In the [aerospace](#) and [medical device](#) industries, many high-precision manufacturers face additional guidelines, specifications, regulations and accreditation standards when passivating their products. One such accreditation is [NADCAP](#), or National Aerospace and Defense Contractors Accreditation Program. Use of an [automated passivation system](#) ensures tight, documented process control parameters to meet validation requirements.

Process Validation FAQs

- [What's involved in the passivation validation process?](#)
- [Why are automated systems easier to process validate than manual equipment?](#)

Industry Standards – Passivation Specifications

Looking for a **stainless steel passivation specification**? Numerous industry standards exist to provide a “how-to-passivate” definition. The most commonly used standards are ASTM A967 and AMS 2700.

Standard	Title / Description
ASTM A967	Standard Specification for Chemical Passivation Treatments for Stainless Steel Parts <ul style="list-style-type: none">Based on U.S. Defense Department standard QQ-P-35One of the most common passivation specifications
AMS 2700	Passivation of Corrosion Resistant Steels <ul style="list-style-type: none">Aerospace Material Specification
ASTM A380	Standard Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment, and Systems <ul style="list-style-type: none">Refers to ASTM A967 for specifics of how to perform passivation
AMS-QQ-P-35	(superseded) Passivation Treatments for Corrosion-Resistant Steel <ul style="list-style-type: none">Takes the place of MIL-QQ-P-35, but has since been replaced with AMS 2700
ASTM F86	Standard Practice for Surface Preparation and Marking of Metallic Surgical Implants
ASTM F983	Standard Practice for Permanent Marking of Orthopaedic Implant Components
ASTM B600	Standard Guide for Descaling and Cleaning Titanium and Titanium Alloy Surfaces <ul style="list-style-type: none">Passivation for titanium and titanium alloys is now recognized in the ASTM standard.
AMS-STD-753	Corrosion-Resistant Steel Parts: Sampling, Inspection and Testing for Surface Passivation
BS (British Standard) EN 2516	Aerospace Series: Passivation of Corrosion Resisting Steels and Decontamination of Nickel Base Alloys

Military Specs and Standards

Standard	Refers to	Title / Description
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MIL-HDBK-808	QQ-P-35 MIL-STD-753	<p>Finish, Protective and Codes for Finishing Schemes for Ground and Ground Support Equipment:</p> <ul style="list-style-type: none"> • Section 5.3.2.4.1 • Table II, Finish code numbers F-200, F-201, F-202, F-203, F-204 • Table VIII, Finish code number D-200 • Refers to QQ-P-35 for passivation of stainless steel, which has since been replaced with ASTM A967 and AMS 2700. • Refers to MIL-STD-753 for testing of passivation, which has since been replaced with AMS-STD-753
MIL-DTL-14072	ASTM A380	<p>Finishes for Ground Based Electronic Equipment:</p> <ul style="list-style-type: none"> • Table IV, Finish number E300
MIL-DTL-5002	ASTM A967 AMS 2700	<p>Surface Treatments and Inorganic Coatings For Metal Surfaces of Weapons Systems:</p> <ul style="list-style-type: none"> • Section 3.8.6
MIL-STD-171	ASTM A967 AMS 2700 ASTM A380	<p>Finishing of Metal and Wood Surfaces:</p> <ul style="list-style-type: none"> • Section 5.1.4.2 • Table V, Finish numbers 5.4.1 and 5.5.1

Industry-Leading Expertise

Aerospace and medical device manufacturers depend on Best Technology's expertise for equipment and process design and development. **Inquire today** for more information on how your company can benefit from our passivation equipment and process design.

Redox: From Wikipedia, the free encyclopedia

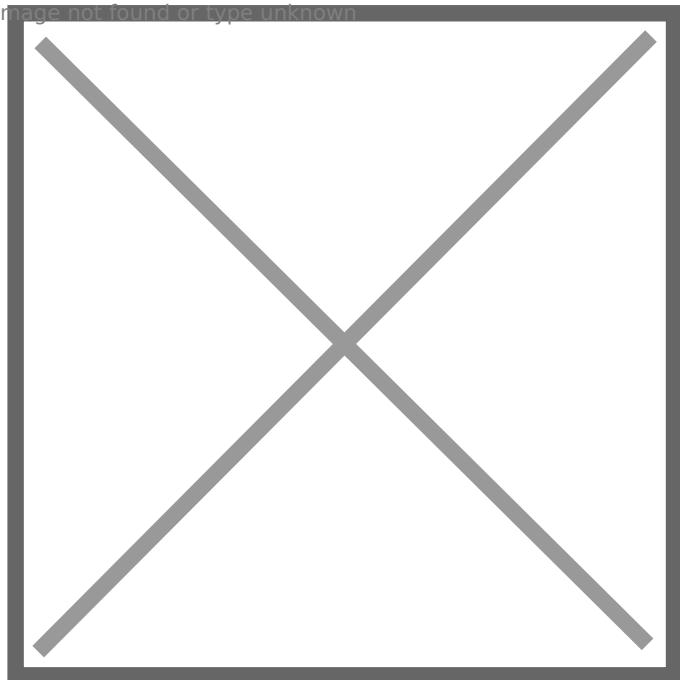
Source: <https://en.wikipedia.org/wiki/Redox>

From Wikipedia, the free encyclopedia

[Jump to navigation](#)[Jump to search](#)

For other uses, see [Redox \(disambiguation\)](#).

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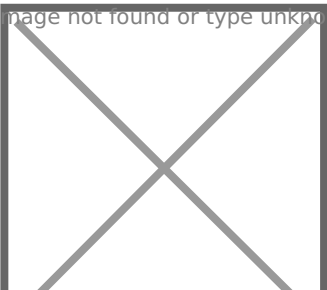


Sodium and fluorine bonding ionically to form [sodium fluoride](#). Sodium loses its outer [electron](#) to give it a stable [electron configuration](#), and this electron enters the fluorine atom [exothermically](#). The oppositely charged ions are then attracted to each other. The sodium is oxidized; and the fluorine is reduced.

0:47

Demonstration of the reaction between a strong oxidizing and a reducing agent. When a few drops of [glycerol](#) (mild reducing agent) are added to powdered [potassium permanganate](#) (strong oxidizing agent), a violent redox reaction accompanied by self-ignition starts.

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Example of a reduction–oxidation reaction between sodium and chlorine, with the *OIL RIG* mnemonic[1]

Redox (**reduction–oxidation**, /ˈrɛdɒks/ *RED-oks*, /ˈriːdɒks/ *REE-doks*[2]) is a type of chemical reaction in which the oxidation states of substrate change.[3]

- **Oxidation** is the *loss* of electrons or an *increase* in the oxidation state of a chemical or atoms within it.
- **Reduction** is the *gain* of electrons or a *decrease* in the oxidation state of a chemical or atoms within it.

There are two classes of redox reactions:

- *electron-transfer* where only one (usually) electron flows from the reducing agent to the oxidant. This type of redox reaction is often discussed in term of redox couples and electrode potentials.
- *atom transfer*, where an atom transfers from one substrate to another. For example, in the *rusting* of iron, the oxidation state of iron atoms increases as it converts to an oxide and simultaneously the oxidation state of oxygen decreases as it accepts electrons released by iron. Although oxidation reactions are commonly associated with the formation of oxides, other chemical species can serve the same function.[4] In *hydrogenation*, C=C (and other) bonds are reduced by transfer of hydrogen atoms.



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Terminology

"Redox" is a [combination](#) of the words "reduction" and "oxidation". The term "redox" was first used in 1928.^[5] The processes of oxidation and reduction occur simultaneously and cannot occur independently.^[4] In redox processes, the reductant transfers electrons to the oxidant. Thus, in the reaction, the reductant or *reducing agent* loses electrons and is oxidized, and the oxidant or *oxidizing agent* gains electrons and is reduced. The pair of an oxidizing and reducing agent that is involved in a particular reaction is called a *redox pair*. A *redox couple* is a reducing species and its corresponding oxidizing form,^[6] e.g., Fe^{2+}

/ Fe^{3+}

.The oxidation alone and the reduction alone are each called a *half-reaction* because two half-reactions always occur together to form a whole reaction.

Oxidants

Oxidation originally implied reaction with oxygen to form an oxide. Later, the term was expanded to encompass oxygen-like substances that accomplished parallel chemical reactions. Ultimately, the meaning was generalized to include all processes involving the loss of electrons. Substances that have the ability to *oxidize* other substances (cause them to lose electrons) are said to be *oxidative* or *oxidizing*, and are known as [oxidizing agents](#), oxidants, or oxidizers. The oxidant (oxidizing agent) removes electrons from another substance, and is thus itself reduced. And,

because it "accepts" electrons, the oxidizing agent is also called an [electron acceptor](#). Oxidants are usually chemical substances with elements in high oxidation states (e.g., H

2O

$2, \text{MnO}^-$

$4, \text{CrO}$

$3, \text{Cr}$

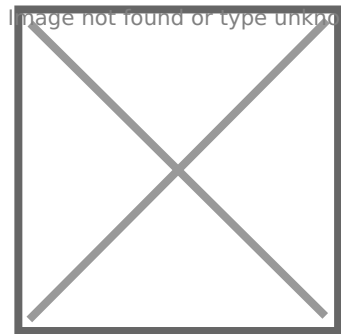
2O^{2-}

$7, \text{OsO}$

4), or else highly [electronegative](#) elements (O_2 , F_2 , Cl_2 , Br_2) that can gain extra electrons by oxidizing another substance.^{[*[citation needed](#)*]}

Oxidizers are oxidants but the term is mainly reserved for sources of oxygen, particularly in the context of explosions. [Nitric acid](#) is an oxidizer.

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The international pictogram for oxidizing chemicals

Main article: [Oxidizing agent](#)

Oxygen is the quintessential oxidizer.

Reducers

Main article: [Reducing agent](#)

Substances that have the ability to *reduce* other substances (cause them to gain electrons) are said to be *reductive* or *reducing* and are known as [reducing agents](#), reductants, or reducers. The reductant (reducing agent) transfers electrons to another substance and is thus itself oxidized.

And, because it donates electrons, the reducing agent is also called an [electron donor](#). Electron donors can also form [charge transfer complexes](#) with electron acceptors. The word *reduction*

originally referred to the loss in weight upon heating a metallic [ore](#) such as a [metal oxide](#) to extract the metal. In other words, ore was "reduced" to metal. [Antoine Lavoisier](#) demonstrated that this loss of weight was due to the loss of oxygen as a gas. Later, scientists realized that the metal

atom gains electrons in this process. The meaning of *reduction* then became generalized to include all processes involving a gain of electrons. **Reducing equivalent** refers to chemical species which transfer the equivalent of one electron in redox reactions. The term is common in biochemistry.[7] A reducing equivalent can be an electron, a hydrogen atom, as a hydride ion.[8]

Reductants in chemistry are very diverse. Electropositive elemental metals, such as lithium, sodium, magnesium, iron, zinc, and aluminium, are good reducing agents. These metals donate or *give away* electrons relatively readily. They transfer electrons.

Hydride transfer reagents, such as NaBH_4 and LiAlH_4 , reduce by atom transfer: they transfer the equivalent of hydride or H^- . These reagents widely used in [the reduction of carbonyl compounds to alcohols.[9][10] A related method of reduction involves the use of hydrogen gas (H_2) as sources of H atoms.

Electronation and deelectronation

The electrochemist John Bockris proposed the words *electronation* and *deelectronation* to describe reduction and oxidation processes, respectively, when they occur at electrodes.[11] These words are analogous to protonation and deprotonation.[12] They have not been widely adopted by chemists worldwide, although IUPAC has recognized the term electronation.[13]

Rates, mechanisms, and energies

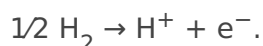
Redox reactions can occur slowly, as in the formation of rust, or rapidly, as in the case of burning fuel. Electron transfer reactions are generally fast, occurring within the time of mixing.

The mechanisms of atom-transfer reactions are highly variable because many kinds of atoms can be transferred. Such reactions can also be quite complex, i.e. involve many steps. The mechanisms of electron-transfer reactions occur by two distinct pathways, inner sphere electron transfer and outer sphere electron transfer.

Analysis of bond energies and ionization energies in water allow calculation of the thermodynamic aspects of redox reactions.

Standard electrode potentials (reduction potentials)

Each half-reaction has a *standard electrode potential* (E°_{cell}), which is equal to the potential difference or **voltage** at equilibrium under **standard conditions** of an **electrochemical cell** in which the **cathode** reaction is the **half-reaction** considered, and the **anode** is a **standard hydrogen electrode** where hydrogen is oxidized:



The electrode potential of each half-reaction is also known as its *reduction potential* E°_{red} , or potential when the half-reaction takes place at a cathode. The reduction potential is a measure of the tendency of the oxidizing agent to be reduced. Its value is zero for $\text{H}^+ + \text{e}^- \rightarrow \frac{1}{2} \text{H}_2$ by definition, positive for oxidizing agents stronger than H^+ (e.g., +2.866 V for F_2) and negative for oxidizing agents that are weaker than H^+ (e.g., -0.763 V for Zn^{2+}).^[14]

For a redox reaction that takes place in a cell, the potential difference is:

$$E^\circ_{\text{cell}} = E^\circ_{\text{cathode}} - E^\circ_{\text{anode}}$$

However, the potential of the reaction at the anode is sometimes expressed as an *oxidation potential*:

$$E^\circ_{\text{ox}} = -E^\circ_{\text{red}}$$

The oxidation potential is a measure of the tendency of the reducing agent to be oxidized but does not represent the physical potential at an electrode. With this notation, the cell voltage equation is written with a plus sign

$$E^\circ_{\text{cell}} = E^\circ_{\text{red(cathode)}} + E^\circ_{\text{ox(anode)}}$$

Examples of redox reactions

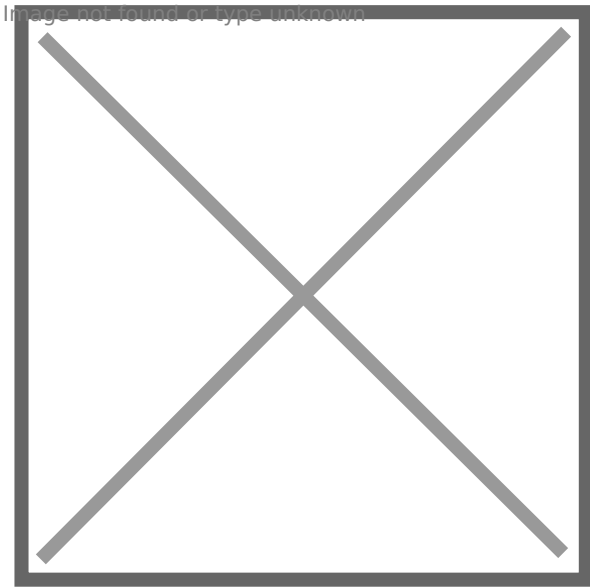
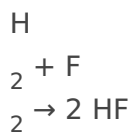
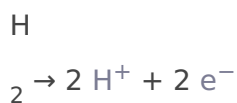


Illustration of a redox reaction

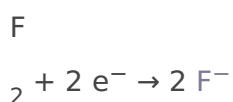
In the reaction between **hydrogen** and **fluorine**, hydrogen is being oxidized and fluorine is being reduced:



This reaction is spontaneous and releases 542 kJ per 2 g of hydrogen because the H-F bond is much stronger than the F-F bond. This reaction can be analyzed as two **half-reactions**. The oxidation reaction converts hydrogen to protons:



The reduction reaction converts fluorine to the fluoride anion:



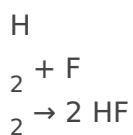
The half reactions are combined so that the electrons cancel:

H_2	\rightarrow	$2 \text{H}^+ + 2 \text{e}^-$
$\text{F}_2 + 2 \text{e}^-$	\rightarrow	2F^-
<hr/>		
$\text{H}_2 + \text{F}_2$	\rightarrow	$2 \text{H}^+ + 2 \text{F}^-$

The protons and fluoride combine to form **hydrogen fluoride** in a non-redox reaction:

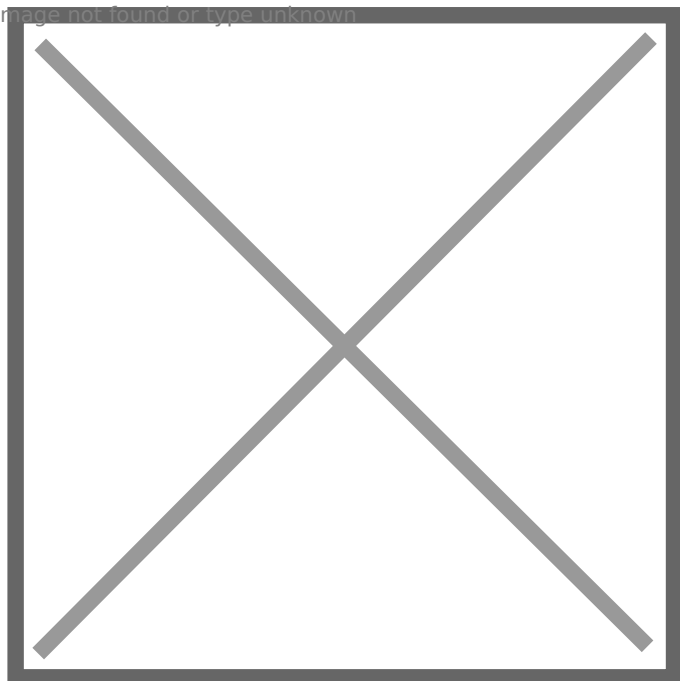


The overall reaction is:



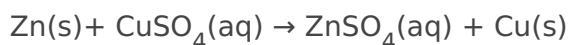
Metal displacement

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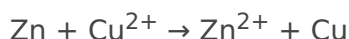
A redox reaction is the force behind an **electrochemical cell** like the **Galvanic cell** pictured. The battery is made out of a zinc electrode in a ZnSO_4 solution connected with a wire and a porous disk to a copper electrode in a CuSO_4 solution.

In this type of reaction, a metal atom in a compound (or in a solution) is replaced by an atom of another metal. For example, **copper** is deposited when **zinc** metal is placed in a **copper(II) sulfate** solution:

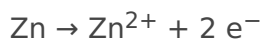


In the above reaction, zinc metal displaces the copper(II) ion from copper sulfate solution and thus liberates free copper metal. The reaction is spontaneous and releases 213 kJ per 65 g of zinc.

The ionic equation for this reaction is:



As two **half-reactions**, it is seen that the zinc is oxidized:



And the copper is reduced:



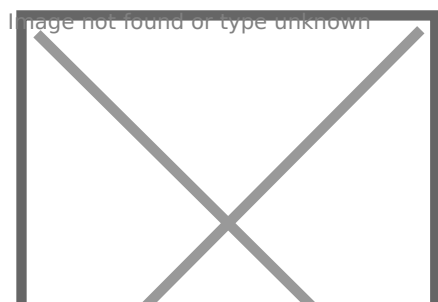
Other examples

- The reduction of **nitrate** to **nitrogen** in the presence of an acid (denitrification):

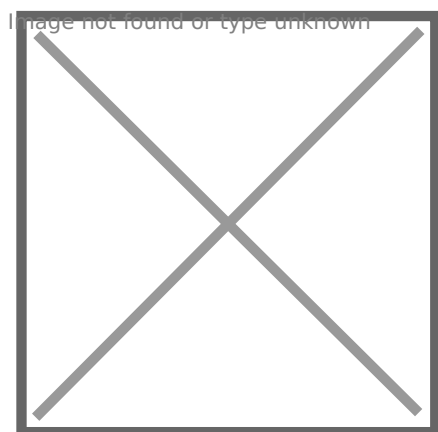


- The **combustion** of **hydrocarbons**, such as in an **internal combustion engine**, produces **water**, **carbon dioxide**, some partially oxidized forms such as **carbon monoxide**, and **heat energy**. Complete oxidation of materials containing **carbon** produces carbon dioxide.
- The stepwise oxidation of a hydrocarbon by oxygen, in **organic chemistry**, produces water and, successively: an **alcohol**, an **aldehyde** or a **ketone**, a **carboxylic acid**, and then a **peroxide**.

Corrosion and rusting



Oxides, such as iron(III) oxide or rust, which consists of hydrated iron(III) oxides $\text{Fe}_2\text{O}_3 \cdot n\text{H}_2\text{O}$ and iron(III) oxide-hydroxide ($\text{FeO}(\text{OH})$, $\text{Fe}(\text{OH})_3$), form when oxygen combines with other elements

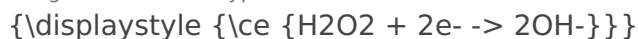
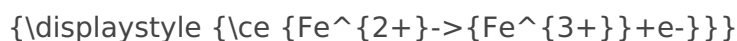


Iron rusting in pyrite cubes

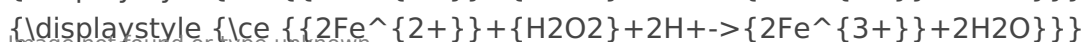
- The term **corrosion** refers to the electrochemical oxidation of metals in reaction with an oxidant such as oxygen. **Rusting**, the formation of iron oxides, is a well-known example of electrochemical corrosion; it forms as a result of the oxidation of iron metal. Common rust often refers to iron(III) oxide, formed in the following chemical reaction:



- The oxidation of iron(II) to iron(III) by hydrogen peroxide in the presence of an acid:

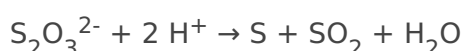


Here the overall equation involves adding the reduction equation to twice the oxidation equation, so that the electrons cancel:



Disproportionation

A **disproportionation** reaction is one in which a single substance is both oxidized and reduced. For example, thiosulfate ion with sulfur in oxidation state +2 can react in the presence of acid to form elemental sulfur (oxidation state 0) and sulfur dioxide (oxidation state +4).



Thus one sulfur atom is reduced from +2 to 0, while the other is oxidized from +2 to +4.[15]

Redox reactions in industry

Cathodic protection is a technique used to control the corrosion of a metal surface by making it the cathode of an electrochemical cell. A simple method of protection connects protected metal to a more easily corroded "**sacrificial anode**" to act as the anode. The sacrificial metal instead of the protected metal, then, corrodes. A common application of cathodic protection is in **galvanized steel**, in which a sacrificial coating of zinc on steel parts protects them from rust.^[*citation needed*]

Oxidation is used in a wide variety of industries such as in the production of **cleaning products** and oxidizing **ammonia** to produce **nitric acid**.

Redox reactions are the foundation of **electrochemical cells**, which can generate electrical energy or support **electrosynthesis**. Metal **ores** often contain metals in oxidized states such as oxides or sulfides, from which the pure metals are extracted by **smelting** at high temperature in the presence of a reducing agent. The process of **electroplating** uses redox reactions to coat objects with a thin layer of a material, as in **chrome-plated automotive parts**, **silver plating cutlery**, **galvanization** and **gold-plated jewelry**.^[*citation needed*]

Redox reactions in biology

ascorbic acid

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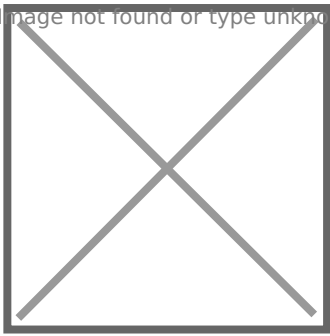
dehydroascorbic acid

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Top: ascorbic acid (reduced form of Vitamin C)

Bottom: dehydroascorbic acid (oxidized form of Vitamin C)

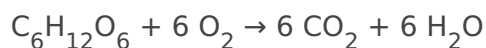
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Enzymatic browning is an example of a redox reaction that takes place in most fruits and vegetables.

Many important biological processes involve redox reactions. Before some of these processes can begin iron must be assimilated from the environment.[16]

Cellular respiration, for instance, is the oxidation of glucose ($C_6H_{12}O_6$) to CO_2 and the reduction of oxygen to water. The summary equation for cell respiration is:



The process of cell respiration also depends heavily on the reduction of NAD^+ to NADH and the reverse reaction (the oxidation of NADH to NAD^+). Photosynthesis and cellular respiration are complementary, but photosynthesis is not the reverse of the redox reaction in cell respiration:



Biological energy is frequently stored and released by means of redox reactions. Photosynthesis involves the reduction of carbon dioxide into sugars and the oxidation of water into molecular oxygen. The reverse reaction, respiration, oxidizes sugars to produce carbon dioxide and water. As intermediate steps, the reduced carbon compounds are used to reduce nicotinamide adenine dinucleotide (NAD^+) to NADH, which then contributes to the creation of a proton gradient, which drives the synthesis of adenosine triphosphate (ATP) and is maintained by the reduction of oxygen. In animal cells, mitochondria perform similar functions. See the *Membrane potential* article.

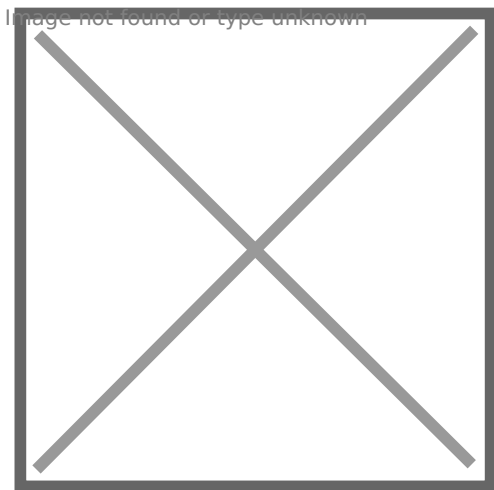
Free radical reactions are redox reactions that occur as a part of homeostasis and killing microorganisms, where an electron detaches from a molecule and then reattaches almost instantaneously. Free radicals are a part of redox molecules and can become harmful to the human body if they do not reattach to the redox molecule or an antioxidant. Unsatisfied free radicals can spur the mutation of cells they encounter and are, thus, causes of cancer.

The term *redox state* is often used to describe the balance of GSH/GSSG, NAD^+/NADH and $\text{NADP}^+/\text{NADPH}$ in a biological system such as a cell or organ. The redox state is reflected in the balance of several sets of metabolites (e.g., lactate and pyruvate, beta-hydroxybutyrate, and acetoacetate), whose interconversion is dependent on these ratios. An abnormal redox state can develop in a variety of deleterious situations, such as hypoxia, shock, and sepsis. Redox mechanism also control some cellular processes. Redox proteins and their genes must be co-located for redox regulation according to the CoRR hypothesis for the function of DNA in mitochondria and chloroplasts.

Redox cycling

Wide varieties of aromatic compounds are enzymatically reduced to form free radicals that contain one more electron than their parent compounds. In general, the electron donor is any of a wide variety of flavoenzymes and their coenzymes. Once formed, these anion free radicals reduce molecular oxygen to superoxide and regenerate the unchanged parent compound. The net reaction is the oxidation of the flavoenzyme's coenzymes and the reduction of molecular oxygen to form superoxide. This catalytic behavior has been described as a futile cycle or redox cycling.

Redox reactions in geology

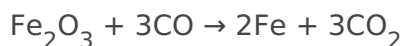


Blast furnaces of Třinec Iron and Steel Works, Czech Republic

Minerals are generally oxidized derivatives of metals. Iron is mined as its magnetite (Fe_3O_4).

Titanium is mined as its dioxide, usually in the form of rutile (TiO_2). To obtain the corresponding metals, these oxides must be reduced, which is often achieved by heating these oxides with carbon or carbon monoxide as reducing agents. Blast furnaces are the reactors where iron oxides and coke (a form of carbon) are combined to produce molten iron. The main chemical reaction producing the

molten iron is:[17]



Redox reactions in soils[edit]

Electron transfer reactions are central to myriad processes and properties in soils, and electron "activity", quantified as Eh (platinum electrode potential (voltage) relative to the standard hydrogen electrode) or pe (analogous to pH as -log electron activity), is a master variable, along with pH, that controls and is governed by chemical reactions and biological processes. Early theoretical research with applications to flooded soils and paddy rice production was seminal for subsequent work on thermodynamic aspects of redox and plant root growth in soils.[18] Later work built on this foundation, and expanded it for understanding redox reactions related to heavy metal oxidation state changes, pedogenesis and morphology, organic compound degradation and formation, free radical chemistry, wetland delineation, soil remediation, and various methodological approaches for characterizing the redox status of soils.[19][20]

Mnemonics[edit]

Main article: [List of chemistry mnemonics](#)

The key terms involved in redox can be confusing.[21][22] For example, a reagent that is oxidized loses electrons; however, that reagent is referred to as the reducing agent. Likewise, a reagent that is reduced gains electrons and is referred to as the oxidizing agent.[23] These mnemonics are commonly used by students to help memorise the terminology:[24]

- "OIL RIG" — **o**xidation **i**s **l**oss of electrons, **r**eduction **i**s **g**ain of electrons[21][22][23][24]
- "LEO the lion says GER [grr]" — **l**oss of **e**lectrons is **o**xidation, **g**ain of **e**lectrons is **r**eduction[21][22][23][24]
- "LEORA says GEROA" — the loss of electrons is called oxidation (reducing agent); the gain of electrons is called reduction (oxidizing agent).[23]
- "RED CAT" and "AN OX", or "AnOx RedCat" ("an ox-red cat") — reduction occurs at the cathode and the anode is for oxidation
- "RED CAT gains what AN OX loses" - reduction at the cathode gains (electrons) what anode oxidation loses (electrons)

- "PANIC" – Positive Anode and Negative is Cathode. This applies to electrolytic cells which release stored electricity, and can be recharged with electricity. PANIC does not apply to cells that can be recharged with redox materials. These galvanic or voltaic cells, such as fuel cells, produce electricity from internal redox reactions. Here, the positive electrode is the cathode and the negative is the anode.

Redox in a Water Fuel Cell

Capacitors are devices used to store electrical energy. They consist of two conductive plates separated by a dielectric material. When a voltage is applied across the plates, an electric field is created, which causes the plates to store energy. Capacitors are commonly used in electronic circuits for filtering, timing, and energy storage.

A water-filled capacitor is a special type of capacitor in which one of the conductive plates is replaced with water. The water serves as the dielectric material, and the other plate is usually made of metal. When an electric field is applied to the water-filled capacitor, an interesting phenomenon occurs: a red material forms at the interface between the water and the metal plate.

The red material that forms in a water-filled capacitor is due to a redox reaction. Redox is short for reduction-oxidation, which is a chemical reaction in which one substance loses electrons (oxidation) and another substance gains electrons (reduction). In a water-filled capacitor, the metal plate serves as the oxidizing agent, and the water serves as the reducing agent.

The source of the red material that forms in a water-filled capacitor is the metal plate. When an electric field is applied across the plates of the capacitor, electrons flow from the negative plate to the positive plate. The metal plate, which is the positive plate, attracts electrons from the water, which is the negative plate. As electrons are transferred from the water to the metal plate, the water becomes positively charged and the metal plate becomes negatively charged.

The transfer of electrons from the water to the metal plate causes a redox reaction to occur. The metal plate oxidizes the water, causing the water to lose electrons. The electrons that are lost by the water are then transferred to the metal plate, causing it to reduce. The red material that forms at the interface between the water and the metal plate is the product of this redox reaction.

The red material that forms in a water-filled capacitor can be a variety of compounds, depending on the metal used in the capacitor. For example, if the metal plate is made of iron, the red material that forms is likely to be iron oxide or rust. If the metal plate is made of copper, the red material that forms is likely to be copper oxide.

In conclusion, the red material that forms in a water-filled capacitor when an electric field is applied is due to a redox reaction between the metal plate and the water. The metal plate acts as the oxidizing agent, and the water acts as the reducing agent. The red material that forms is the product of this reaction, and its composition depends on the metal used in the capacitor. While the formation of the red material may be interesting to observe, it can also have a negative impact on the performance of the capacitor, as it can reduce its capacitance and increase its resistance.

Types of Stainless Steel

Production

Stainless Steel 304L, also known as AISI 304L or SUS 304L, is a common type of austenitic stainless steel. Austenitic stainless steels are composed mostly of iron, along with significant amounts of chromium and nickel. They may also contain other elements like manganese, silicon, and carbon.

Here's a brief overview of the process to make austenitic stainless steel like 304L and the annealing process involved:

1. Production of 304L Stainless Steel

The production of stainless steel involves a series of processes:

Melting: Raw materials (iron ore, chromium, nickel, etc.) are melted together in an electric furnace. The specific amounts of each material depend on the desired final composition of the steel. For 304L stainless steel, the composition is typically about 18-20% chromium, 8-12% nickel, and the remainder iron, with small amounts of carbon, manganese, silicon, and other elements.

Forming: The molten steel is then cast into a semi-finished form, such as a slab or billet. This is usually done by pouring the molten steel into a mold and allowing it to cool.

Hot Rolling: The semi-finished steel is heated to a high temperature and then rolled to reduce its thickness and achieve the desired shape, such as a sheet, bar, or wire.

2. Annealing of 304L Stainless Steel

Annealing is a heat treatment process that changes the physical and sometimes chemical properties of a material to increase its ductility and reduce its hardness, making it more workable.

In the case of 304L stainless steel, the annealing process would typically involve the following steps:

Heating: The steel is heated to a specific temperature within the range of 1850-2050°F (1010-1120°C). This temperature is above the recrystallization point of the steel.

Soaking: The steel is held at this high temperature for a period of time. This allows the heat to penetrate the steel thoroughly and relieves internal stresses within the metal.

Cooling: The steel is then cooled. This is usually done by quenching in water or air, although other methods may also be used. The rapid cooling helps to prevent the formation of precipitates that

could reduce the corrosion resistance of the steel.

3. Assembling the Minerals

Austenite is a solid solution of iron and other elements, primarily carbon and sometimes alloying elements like nickel. In 304L stainless steel, the high chromium and nickel contents promote the formation of the austenite phase. The austenite phase is face-centered cubic in structure and is known for its excellent ductility and toughness, even at low temperatures.

It's important to note that the specific processes and conditions used to produce stainless steel can vary depending on the desired properties of the final product and the specific practices of the manufacturer.

General Conditioning Principles

In the case of water-filled capacitors, the buildup of white or silver powder on the metal electrodes after prolonged use is actually a desired effect for certain applications. This powder formation is typically the result of corrosion or oxidation of the metal electrode in the presence of dissolved oxygen and chlorine.

The 304L stainless steel electrodes commonly used in water-filled capacitors are susceptible to corrosion and oxidation, which can result in the formation of oxides and chlorides on the metal surface. This buildup of white or silver powder is often an indication that the metal electrode is becoming more resistive and less conductive, which can ultimately result in a decrease in capacitance.

However, in certain applications, this decrease in capacitance can be beneficial. For example, in energy storage applications, a decrease in capacitance can be used to limit the amount of current that flows through the capacitor, which can help to prevent damage to the capacitor and the surrounding circuitry.

In addition, the formation of white or silver powder can also affect the properties of the metal-semiconductor junction, which can result in rectification properties and the ability to convert AC power to DC power. This effect is particularly useful in power conversion applications, where the ability to convert between AC and DC power is critical.

The buildup of white or silver powder on the metal electrodes in water-filled capacitors can be a desired effect for certain applications. This effect is typically the result of corrosion or oxidation of the metal electrode, which can decrease capacitance and increase resistance. However, in some cases, this decrease in capacitance and increase in resistance can be beneficial for energy storage and power conversion applications.

It is theoretically possible for Cr_2O_3 to be produced from natural water in a capacitor when exposed to electric fields at varying frequencies, but it would depend on a variety of factors such as the composition of the water, the materials used in the capacitor, and the specific frequencies and amplitudes of the electric fields applied.

Chromium is a common impurity in natural water, and under certain conditions, it can react with oxygen and water to form chromium oxide (Cr_2O_3). The formation of Cr_2O_3 in a capacitor would likely require the presence of chromium ions in the water and an electric field strong enough to induce chemical reactions at the metal-water interface.

The specific frequencies and amplitudes of the electric fields applied could also play a role in the formation of Cr₂O₃. For example, higher frequencies and amplitudes could increase the likelihood of chemical reactions occurring, while lower frequencies and amplitudes could have little to no effect.

The materials used in the capacitor could also affect the formation of Cr₂O₃. For example, if the electrodes are made of a material that readily reacts with chromium, such as iron or nickel, then the formation of Cr₂O₃ could be more likely.

See [Wikipedia](#) for more information on Cr₂O₃.