



# How Best to Maintain a Metal Bridge?

## Student Worksheet on the Rusting of Iron

This worksheet is guiding you to seek answers to 2 research questions:

1. *What are the factors which I predict affect the rusting of iron?*
2. *How can I gain evidence about whether the factors I predict affect the rusting of iron do in fact affect the rusting of iron ?*

Carefully read each section and provide suitable answers within the boxes.

1. The normal procedure to gain evidence for the rusting of iron is to eliminate one factor at a time and see the outcome. How can you do this in the case of :

	Factor affecting rusting to be eliminated	Method by which this factor can be eliminated
1	Air	
2	Water	
3	(Others)	
4	(Others)	
5	(Others)	

2. Explain whether you think a control experiment is required. And if you think a control experiment is needed, how will you set this up?

I think a control experiment (is/ is not) needed

**Developer: Jack Holbrook**

Institute: ICASE

Country: UK



- 3 Give you predicted observations, after some days, for each experiment you set up

	Factor affecting rusting to be eliminated	Predicted observation
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1	Air	
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2	Water	
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3		
---	--	--

4		
---	--	--

5		
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4. State what you actually did in your experiments.

Indicate the apparatus you used (a labelled diagram may be helpful for this)

The procedure you followed in each experiment

(DO THIS ON THE SEPARATE SHEET PROVIDED)

1. Write a conclusion to your series of experiments by answering the question 'What factors are needed for the rusting of iron'?

2. Give your suggested formula for rust.

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**Developer: Jack Holbrook**

Institute: ICASE

Country: UK

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## SEPARATE SHEET

State what you did in your experiments.

You can use well labelled diagrams to illustrate the apparatus and chemicals used, but you must also describe what you did.

**Developer: Jack Holbrook**

Institute: ICASE

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## Possibilities for Maintaining the Bridge

- I Do nothing. The bridge will rust and will need replacing after 6 years.
- II Once the bridge is built, give the bridge 2 costs of paint. As the painting is affected by weather, it is predicted that repainting will be necessary every 3 years.
- III Once the bridge is erected, carefully remove all signs of rust by sandblasting and then applying a primer paint and 2 coats of ordinary paint. It is predicted this will last for 6 years and the process will need to be repeated.
- IV Before the bridge is erected, sandblast and galvanise the metal. It is predicted the bridge will last for at least 20 years without further attention.

## Supporting data that may be useful

Costs at 1994 prices (in US\$)

Metal for the bridge	=	80000
Construction cost	=	10000
Paint for the bridge	=	6000
Sandblasting charge	=	4000
Galvanising cost + labour	=	21000
Cost of the scrap metal	=	2000
Cost of labour for painting	=	1000
Cost of labour for sandblasting	=	1000
Interest payments on loans	=	7%

## Calculations

A. Cost (in US\$) of maintaining the bridge, with time, for each of the four possibilities

Option	1	2	3	4
Initial cost	90	97	102	123
After 3 yrs	90	104	102	123
After 6 yrs	178	111	114	123
After 9 yrs	178	118	114	123
After 12 yrs	266	125	126	123
After 15 yrs	266	132	126	123

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B. Costs (in US\$) if the initial cost is borrowed, and interest repayments are made yearly

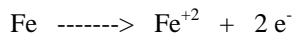
Initial cost	90	97	102	123
After 3 yrs	108	124	123	149
After 6 yrs	196	151	156	175
After 9 yrs	214	178	177	201
After 12 yrs	338	205	210	227
15 yrs	356	232	231	253

## Corrosion

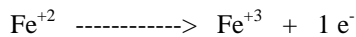
Corrosion occurs in the presence of moisture. For example when iron is exposed to moist air, it reacts with oxygen to form rust,



The amount of water complexed with the iron (III) oxide (ferric oxide) varies as indicated by the letter "X". The amount of water present also determines the color of rust, which may vary from black to yellow to orange brown. The formation of rust is a very complex process which is thought to begin with the oxidation of iron to ferrous (iron "+2") ions.



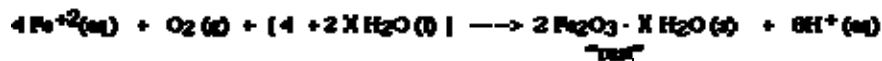
Both water and oxygen are required for the next sequence of reactions. The iron (+2) ions are further oxidized to form ferric ions (iron "+3") ions.



The electrons provided from both oxidation steps are used to reduce oxygen as shown.



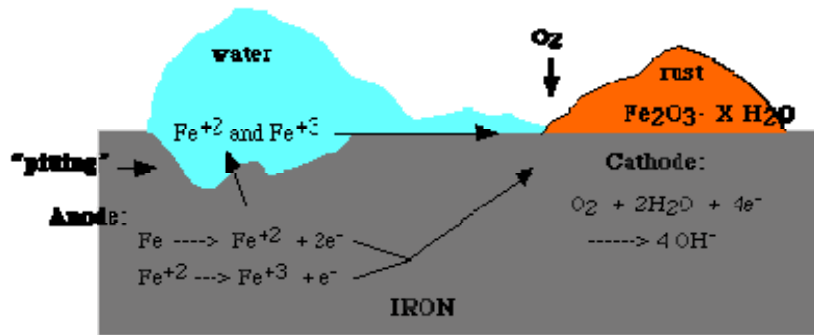
The ferric ions then combine with oxygen to form ferric oxide [iron (III) oxide] which is then hydrated with varying amounts of water. The overall equation for the rust formation may be written as :



The formation of rust can occur at some distance away from the actual pitting or erosion of iron as illustrated below. This is possible because the electrons produced via the initial oxidation of iron can be conducted through the metal and the iron ions can diffuse through the water layer to another point on the metal surface where oxygen is available. This process results in an electrochemical cell in which iron serves as the anode, oxygen gas as the cathode, and the aqueous solution of ions serving as a "salt bridge" as shown below.

**Developer: Jack Holbrook**

Institute: ICASE  
Country: UK



The involvement of water accounts for the fact that rusting occurs much more rapidly in moist conditions as compared to a dry environment such as a desert. Many other factors affect the rate of corrosion. For example the presence of salt greatly enhances the rusting of metals. This is due to the fact that the dissolved salt increases the conductivity of the aqueous solution formed at the surface of the metal and enhances the rate of electrochemical corrosion. This is one reason why iron or steel tend to corrode much more quickly when exposed to salt (such as that used to melt snow or ice on roads) or moist salty air near the ocean.

## Resistance to corrosion



Gold nuggets do not corrode, even on a geological time scale.

The materials most resistant to corrosion are those for which corrosion is thermodynamically unfavorable.

Any corrosion products of gold or platinum tend to decompose spontaneously into pure metal, which is why these elements can be found in metallic form on Earth, and is a large part of their intrinsic value.

More common "base" metals can only be protected by more temporary means.

Some metals have naturally slow reaction kinetics, even though their corrosion is thermodynamically favorable. These include such metals as zinc, magnesium, and cadmium. While corrosion of these metals is continuous and ongoing, it happens at an acceptably slow rate. An extreme example is graphite, which releases large amounts of energy upon oxidation, but has such slow kinetics that it is effectively immune to electrochemical corrosion under normal conditions.

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Institute: ICASE

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## Passivation

Given the right conditions, a thin film of corrosion products can form on a metal's surface spontaneously, acting as a barrier to further oxidation. When this layer stops growing at less than a micrometre thick under the conditions that a material will be used in, the phenomenon is known as passivation (rust, for example, usually grows to be much thicker, and so is not considered passivation, because this mixed oxidized layer is not protective). While this effect is in some sense a property of the material, it serves as an indirect kinetic barrier: the reaction is often quite rapid unless and until an impermeable layer forms. Passivation in air and water at moderate pH is seen in such materials as aluminium, stainless steel, titanium, and silicon.

These conditions required for passivation are specific to the material. Some conditions that inhibit passivation include: high pH for aluminum, low pH or the presence of chloride ions for stainless steel, high temperature for titanium (in which case the oxide dissolves into the metal, rather than the electrolyte) and fluoride ions for silicon. On the other hand, sometimes unusual conditions can bring on passivation in materials that are normally unprotected, as the alkaline environment of concrete does for steel rebar. Exposure to a liquid metal such as mercury or hot solder can often circumvent passivation mechanisms.

## Applied coatings

Plating, painting, and the application of enamel are the most common anti-corrosion treatments. They work by providing a barrier of corrosion-resistant material between the damaging environment and the (often cheaper, tougher, and/or easier-to-process) structural material. Aside from cosmetic and manufacturing issues, there are tradeoffs in mechanical flexibility versus resistance to abrasion and high temperature. Platings usually fail only in small sections, and if the plating is more noble than the substrate (for example, chromium on steel), a galvanic couple will cause any exposed area to corrode much more rapidly than an unplated surface would. For this reason, it is often wise to plate with a more active metal such as zinc or cadmium.

## Reactive coatings

If the environment is controlled (especially in recirculating systems), corrosion inhibitors can often be added to it. These form an electrically insulating and/or chemically impermeable coating on exposed metal surfaces, to suppress electrochemical reactions. Such methods obviously make the system less sensitive to scratches or defects in the coating, since extra inhibitors can be made available wherever metal becomes exposed. Chemicals that inhibit corrosion include some of the salts in hard water (Roman water systems are famous for their mineral deposits), chromates, phosphates, and a wide range of specially-designed chemicals that resemble surfactants (i.e. long-chain organic molecules with ionic end groups).

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## Anodization

Aluminium alloys often undergo a surface treatment. Electrochemical conditions in the bath are carefully adjusted so that uniform pores several nanometers wide appear in the metal's oxide film. These pores allow the oxide to grow much thicker than passivating conditions would allow. At the end of the treatment, the pores are allowed to seal, forming a harder-than-usual surface layer. If this coating is scratched, normal passivation processes take over to protect the damaged area.

## Cathodic protection

Cathodic protection (CP) is a technique to control the corrosion of a metal surface by making that surface the cathode of an electrochemical cell.

It is a method used to protect metal structures from corrosion. Cathodic protection systems are most commonly used to protect steel, water, and fuel pipelines and tanks; steel pier piles, ships, and offshore oil platforms.

For effective CP, the potential of the steel surface is polarized (pushed) more negative until the metal surface has a uniform potential. With a uniform potential, the driving force for the corrosion reaction is halted. For galvanic CP systems, the anode material corrodes under the influence of the steel, and eventually it must be replaced. The polarization is caused by the current flow from the anode to the cathode, driven by the difference in electrochemical potential between the anode and the cathode.

For larger structures, galvanic anodes cannot economically deliver enough current to provide complete protection. Impressed Current Cathodic Protection (ICCP) systems use anodes connected to a DC power source (a cathodic protection rectifier). Anodes for ICCP systems are tubular and solid rod shapes of various specialized materials. These include high silicon cast iron, graphite, mixed metal oxide or platinum coated titanium or niobium coated rod and wires.

## Galvanic corrosion

Galvanic corrosion occurs when two different metals electrically contact each other and are immersed in an electrolyte. In order for galvanic corrosion to occur, an electrically conductive path and an ionically conductive path are necessary. This effects a galvanic couple where the more active metal corrodes at an accelerated rate and the more noble metal corrodes at a retarded rate. When immersed, neither metal would normally corrode as quickly without the electrically conductive connection (usually via a wire or direct contact). Galvanic corrosion is often utilised in sacrificial anodes. What type of metal(s) to use is readily determined by following the galvanic series. For example, zinc is often used as a sacrificial anode for steel structures, such as pipelines or docked naval ships. Galvanic corrosion is of major interest to the marine industry and also anywhere water can contact pipes or metal structures.

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Institute: ICASE  
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Factors such as relative size of anode (smaller is generally less desirable), types of metal, and operating conditions (temperature, humidity, salinity, &c.) will affect galvanic corrosion. The surface area ratio of the anode and cathode will directly affect the corrosion rates of the materials.

## Microbial corrosion

Microbial corrosion, or bacterial corrosion, is a corrosion caused or promoted by microorganisms, usually chemo-autotrophs. It can apply to both metals and non-metallic materials, in both the presence and lack of oxygen. Sulphate-reducing bacteria are common in lack of oxygen; they produce hydrogen sulphide, causing sulphide stress cracking. In presence of oxygen, some bacteria directly oxidize iron to iron oxides and hydroxides, other bacteria oxidize sulphur and produce sulphuric acid causing biogenic sulphide corrosion. Concentration cells can form in the deposits of corrosion products, causing and enhancing galvanic corrosion.

## High temperature corrosion

High temperature corrosion is chemical deterioration of a material (typically a metal) under very high temperature conditions. This non-galvanic form of corrosion can occur when a metal is subject to a high temperature atmosphere containing oxygen, sulphur or other compounds capable of oxidising (or assisting the oxidation of) the material concerned. For example, materials used in aerospace, power generation and even in car engines have to resist sustained periods at high temperature in which they may be exposed to an atmosphere containing potentially highly corrosive products of combustion.

The products of high temperature corrosion can potentially be turned to the advantage of the engineer. The formation of oxides on stainless steels, for example, can provide a protective layer preventing further atmospheric attack, allowing for a material to be used for sustained periods at both room and high temperature in hostile conditions. Such high temperature corrosion products in the form of compacted oxide layer glazes have also been shown to prevent or reduce wear during high temperature sliding contact of metallic (or metallic and ceramic) surfaces.

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