Corrosion: All at Sea: Teacher Notes

Overview/Introduction

The ocean is one of the most natural corrosive environments, made up of dissolved salts (mainly sodium chloride) and carbon dioxide from the atmosphere [Footnote [3]].

Residents living near coastal areas may need to replace metal objects regularly if left outside for prolonged periods due to corrosion (e.g. cars, bikes, garden tools, BBQ's, golf clubs). Families or businesses that rely on boats and/or other leisure watercraft (e.g. jet skis, yachts, ships) with metallic parts have to deter or protect against the effects of corrosion.

Marine archaeologists find metal artefacts and shipwrecks with severe corrosion due to the prolonged time spent submerged in the ocean

The Australasian Corrosion Association (ACA) is a not-for-profit professional association with 2,000 members in Australia and New Zealand. The ACA provides training, seminars, conferences, and publications and disseminates information on corrosion prevention and control.

In order to build its presence in STEM in Secondary Schools, the ACA Foundation is working co-operatively with the ASELL for Schools project, which is a three-year funded project through the federal government's Australian Maths and Science Partnerships Program.

The ACA Foundation is targeting students in years 9 and 10, before they make final subject choices. This fits within ASELL's target group of learners. Like ASELL for Schools, the Foundation is committed to generating excitement and inquiry in the classroom.

---

[3] NOAA (2017). 'Why is the ocean salty?' National Oceanic and Atmospheric Administration, US Department of Commerce. Retrieved 16 July 2017 from https://oceanservice.noaa.gov/facts/whysalty.html.

In this activity, students will simulate and test which environmental conditions influence the rate corrosion of different metals and describe the observed changes.

Curriculum Outcomes: Australian Curriculum F-10

Level 9

Science as a human endeavour

- People use scientific knowledge to evaluate whether they accept claims, explanations or predictions, and advances in science can affect people’s lives, including generating new career opportunities (ACSHE160)
- Values and needs of contemporary society can influence the focus of scientific research (ACSHE228)

Science Understanding: Chemical sciences

- Chemical reactions involve rearranging atoms to form new substances; during a chemical reaction mass is not created or destroyed (ACSSU178)
- Chemical reactions, including combustion and the reactions of acids, are important in both non-living and living systems and involve energy transfer (ACSSU179)

Level 10

Science as a human endeavour

- People use scientific knowledge to evaluate whether they accept claims, explanations or predictions, and advances in science can affect people’s lives, including generating new career opportunities (ACSHE194)
- Values and needs of contemporary society can influence the focus of scientific research (ACSHE230)

Science Understanding: Chemical sciences

- The atomic structure and properties of elements are used to organise them in the Periodic Table (ACSSU186)
- Different types of chemical reactions are used to produce a range of products and can occur at different rates (ACSSU187)

Curriculum Outcomes: Victorian Curriculum F-10

Levels 9 and 10

Science as a human endeavour

- The values and needs of contemporary society can influence the focus of scientific research (VCSSU116)

Science Understanding: Chemical sciences

- The atomic structure and properties of elements are used to organise them in the periodic table (VCSSU123)
- Chemical reactions involve rearranging atoms to form new substances; during a chemical reaction mass is not created or destroyed (VCSSU124)
- Different types of chemical reactions are used to produce a range of products and can occur at different rates; chemical reactions may be represented by balanced chemical equations (VCSSU125)
- Chemical reactions, including combustion and the reactions of acids, are important in both non-living and living systems and involve energy transfer (VCSSU126)

Key Knowledge and Skills

In completing this activity, students explore and apply a range of concepts and terms. Some of these terms and concepts are described, defined and explained below.

Corrosion – The process of destruction or deterioration of a metallic material as a result of chemical reactions with the surrounding environment.

Metal - A substance that usually (1) can conduct electricity, (2) can conduct heat, (2) has shininess (lustre), and can be deformed when struck with a hammer or other hard object (malleability). When metals react, they tend to lose electrons to form positive ions (cations).

Chemical composition – The relative amounts of different elements or substances that are present in a sample.

Alloy - A solid mixture of two or more metals. Some alloys can include non-metal components. Steel is an alloy that consists of iron with small amounts of carbon. Stainless steel is an alloy that consists of iron with small amounts of carbon and about 18% chromium. 18-carat gold in jewellery is an alloy of 75% gold, 7.5% silver and 7.5% copper. Bronze and pewter are other common alloys.

Reactivity series – A ranking of listing of metals from the most reactive to the least reactive.

Solution - A mixture of two or more substances that is homogeneous. Homogeneous means that the solution is evenly mixed and has the same appearance and composition everywhere in the mixture. It is possible to have gas solutions, liquid solutions, and solid solutions. In this laboratory learning activity, **solution** will refer to water-based liquid solutions.

Concentration - The ratio of the amount of a solute in a solvent or total solution. There are many ways of measuring and expressing concentration. In this laboratory learning activity, the concentration will be expressed as the percentage mass per unit volume.

% (m/v) - Percentage mass per volume (%m/v) is one method of measuring concentration, defined as the mass of the solute per 100 mL of solution

$$\text{concentration (\%m/v)} = \frac{\text{mass of dissolved substance (g)}}{\text{volume of solution (mL)}} \times 100\%$$

Dissolve - The process in which the solute interacts with the solvent to form a solution. This only applies to mixtures in which the solute was originally in a different gas/liquid/solid states from the solvent.

Solute – A substance which is dissolved in a solvent to form a solution.

Solvent – The largest component of a liquid or a gas, in which another substance (the solute) is dissolved to form a solution.

Investigation - A scientific process of answering a question, exploring an idea or solving a problem that requires activities such as planning a course of action, collecting data, interpreting data, reaching a conclusion and communicating these activities

Variable - Something that can change.

Dependent variable - Variable that changes in response to changes in the independent variable and that is observed or measured.

Independent variable - Variable that is deliberately changed.

Controlled variables - Variables that are kept constant.

Fair test - When testing different materials all the variables except the one being tested need to be kept the same.

Key Science Inquiry Skills

In conducting this activity, students need to:

- identify variables relevant in the test
- determine the independent, dependent and control variables
- take steps to ensure accuracy in measurement
- record data systematically
- analyse data
- draw conclusions based on evidence

Background information

The ocean is one of the most natural corrosive environments, made up of dissolved salts (mainly sodium chloride) and carbon dioxide from the atmosphere.

It is possible to buy pure metals from chemical suppliers, but the disadvantage of this is that pure metals are **not** part of students' normal lives. Everything they see and touch and use are generally alloys or have paint or other surface coatings. This laboratory learning activity uses metal samples from around the home. It is recommended that a variety of metal samples be used: some that corrode and some that do not. In our testing, it has been found that "bright iron" corrodes reliably every time, even in room temperature demineralised water.

General background information

- **BBC Bitesize** Website.
  - BBC (2014) Making cars: Rusting. Retrieved 26 September 2017 from http://www.bbc.co.uk/schools/gcsebitesize/science/ocr_gateway/chemical_resources/making_carsrev1.shtml.

Industry links

- The **Australasian Corrosion Association (ACA)** Website.
  - https://foundation.corrosion.com.au/.

- Cost of corrosion to the **Australian economy**
    - Curtin University Media Release (2009) 'Research shows that corrosion costs the local Economy' Retrieved 16 July 2017 from http://news.curtin.edu.au/media-releases/research-shows-corrosion-costs-the-local-economy/.
- Role of **corrosion engineers**.
    - National Association of Corrosion Engineers International (n.d.) 'I am NACE-Craig Stevenson' Retrieved 16 July 2017 from https://www.nace.org/Membership/I-AM-NACE---Craig-Stevenson/.
    - Where Women Work (n.d.) 'Unique opportunities via BP's Future Leaders Program' Retrieved 17 July 2017 from https://www.wherewomenwork.com.au/Career/252/BP-Cynthia-Pierre-engineer-australia.

Contemporary science research

- Use of anti-corrosive agents in water treatment.
    - Compound Interest (2016). 'The Chemistry Behind Your Home's Water Supply' Retrieved 17 July 2017 from http://www.compoundchem.com/2016/04/21/water-treatment/.
    - Compound Interest (2016). 'Lead in the Water –The Flint Water Crisis' Retrieved 17 July 2017 from http://www.compoundchem.com/2016/01/25/flint-water/.
- Studying rust in real time.
    - Australian Broadcasting Corporation Science (2002). 'New probe to study rust in 'real-time'' Retrieved 16th July 2017 from http://www.abc.net.au/science/articles/2002/02/20/485323.htm.
- Foiling corrosion involves outsmarting metals nature.
    - Tullo A.H. (17 September 2007). Foiling corrosion involves outsmarting metals' nature. Chemical and Engineering News, 85(38), p. 20. Retrieved 16 July from

http://cen.acs.org/articles/85/i38/Foiling-Corrosion-Involves-Outsmarting-MetalsNature.html.

Science and engineering concepts

Corrosion, electrolysis, reactions in batteries, fuel cells and solar panel, respiration and photosynthesis are all examples of **reduction-oxidation (redox) reactions**.

The name corrosion is used when this reduction-oxidation process is unwanted. When a metal is corroded, its properties will change as it undergoes reaction to form positively-charged ions. The most common type of corrosion occurs when

- A metal is corroded (oxidised) to form either an insoluble oxide or dissolved positively-charged ions (cations). This process involves the metal atoms losing electrons to form positively-charged ions (cations).

- Oxygen, a second metal or some other oxidising agent is reduced. Reduction involves the oxygen atoms, metal atoms or other oxidising agent gaining electrons. If this reduction involves a second metal, this metal is originally present as positively-charged ions, which can be either dissolved in solution or part of a solid mineral or other ionic substance.

The concentration of salt in seawater is about 3.5% (m/v). Significantly higher concentrations are recommended for this activity so that the corrosion can be sufficiently fast to be measureable in part of a class period.

Other naturally occurring corrosive environments

Apart from the ocean, other naturally occurring corrosive environments include acid rain, geysers, volcanic springs, and old mine sites. For example, the hot springs in the Taupo Volcanic Zone near Rotorua, New Zealand, have super-heated water/steam temperatures of up to 500°C and pH ranging from below 2 to over 8 (Footnote [4]).

Hot springs near Ebeko volcano (Paramushir Island, Kuril Islands, Russia) consist of naturally occurring hydrochloric and sulfuric acid mixtures. The hot springs are so acidic that they have *negative* pH values (pH = -1.7) (Footnotes [5,6,7,8]). The world record for the *most negative*

---

[4] Eppelbaum, L., Kutasov, I. & Pilchin, A. (2014) Applied Geothermics. Lecture Notes in Earth System Sciences, DOI: 10.1007/978-3-642-34023-9_2, Berlin: Springer-Verlag.

[5] Ivanov, V. V. (1955). The present hydrothermal activity of the volcano Ebeko on the isle of Paramushir (Kurile Islands). *Geokhimiya*, **1**(1), 63-76 (in Russian); translation in Ivanov, V. V.

environmental pH values (pH = -3.6) are the run-off waters from the abandoned Richmond Mine at Iron Mountain, California (Footnotes [7,8,9,10]).

By comparison, normal rain has a pH of about 5.6; it is slightly acidic because carbon dioxide (CO_2) dissolves into it forming weak carbonic acid. Acid rain usually has a pH between 4.2 and 4.4 (Footnote [11]).

Soft drink and vinegar have pH of about 2.8, and can be used as models for these naturally occurring corrosive environments. This could be an extension activity in Part E.

Non-volcanic natural springs have carbonated water with lots of dissolved carbon dioxide and minerals. Carbonated drinking water can be used as models for these naturally occurring waters. This could be an extension activity in Part E.

Pedagogy

Inquiry Skills

This is an inquiry activity that can be adjusted by the teacher to be as guided or as open-ended as desired. The student notes begin with specific directions but later questions allow students to conduct more independent investigations. The teacher may, however, decide to provide close guidance and direction throughout the activity.

Teachers may use the inquiry scaffolding tool[12] to assist decision making about the degree of support to provide students for each phase of the inquiry process.

(1957) The present hydrothermal activity of the volcano Ebeko on the Isle of Paramushir. *Geochemistry*, **1**, 77-92.

6 Nikitina, L. P. (1974) in the Proceedings of the Water-Rock Interaction Symposium, Prague, Czechoslovakia. P. 196.

7 Lim, K. F. (2006). Negative pH does exist. *Journal of Chemical Education*, **83**(10), 1465.

8 Lim, K. F. (2012). Why students should learn about negative pH. *LabTalk*, **56** (3), 10-14.

9 Nordstrom, D. K., & Alpers, C. N. (1999). Negative pH, efflorescent mineralogy, and consequences for environmental restoration at the Iron Mountain Superfund site, California. *Proceedings of the National Academy of Science* (USA), **96**(7), 3455-3462.

10 Nordstrom, D. K., Alpers, C. N., Ptacek, C. J., & Blowes, D. W. (2000). Negative pH and extremely acidic mine waters from Iron Mountain, California. *Environmental Science and Technology*, **34**(2), 254 -258.

11 United States Environmental Protection Agency (2017) What is Acid Rain? Retrieved 26 July 2017 from https://www.epa.gov/acidrain/what-acid-rain.

12 Inquiry scaffolding tool. National Research Council (2000); Bruck, L.B., Bretz, S.L., & Towns, M. H.,2008. Adapted for the Victorian Curriculum by Lim, K. F. (2016), unpublished.)

Curriculum outcome (slightly paraphrased)	Prescription	Confirmation	Structured Inquiry	Guided Inquiry	Open Inquiry	Curriculum outcome (slightly paraphrased)
Formulate questions or hypotheses (VCSIS134)	No question	Student engages in a question provided by teacher, or other source	Student sharpens or clarifies a question provided by teacher, or other source	Student selects among questions, poses new questions	Student poses a question	Formulate questions or hypotheses (VCSIS134)
Plan, select and use appropriate investigation (VCSIS135)	Student is given plan of investigation	Student uses a plan provided by teacher, or other source	Student sharpens or clarifies a plan provided by teacher, or other source	Student selects among plans, poses new plans	Student plans, selects and uses appropriate investigation	Plan, select and use appropriate investigation (VCSIS135)
Select and use appropriate equipment and collect and record data (VCSIS136)	Student is given data	Student is told how to use equipment and how to collect data	Student is told how to use equipment and asked to collect data	Student is directed to collect certain data and selects appropriate equipment	Student determines what is appropriate equipment and data and collects data	Select and use appropriate equipment and collect and record data (VCSIS136)
Construct and use representations, to record and summarise data (VCSIS137)	Student is given representations and summaries of data	Student told how to represent and summarise data	Student is guided to represent and summarise data	Student selects among representations and summaries	Student determines and uses appropriate representations and summaries	Construct and use representations, to record and summarise data (VCSIS137)
Analyse patterns and trends in data, and draw conclusions (VCSIS138)	Student is given conclusions	Student is given trends in data and told how to draw conclusions	Student is given trends in data and guided towards conclusions	Student is directed to analyse data and selects among possible conclusions	Student analyses data and draws conclusions	Analyse patterns and trends in data, and draw conclusions (VCSIS138)
Use knowledge of scientific concepts to evaluate conclusions (VCSIS139)	Student is given links to scientific concepts and given evaluation	Student is given scientific concepts and told how to evaluate	Student is given scientific concepts and asked to evaluate	Student is directed toward areas and sources of scientific knowledge	Student independently examines other resources and evaluates conclusions	Use knowledge of scientific concepts to evaluate conclusions (VCSIS139)
Communicate scientific ideas and evidence-based arguments (VCSIS140)	No communication	Student is given steps and procedures for communication	Student is provided broad guidelines to use to sharpen communication	Student is coached in development of communication	Student forms reasonable and logical argument to communicate explanation	Communicate scientific ideas and evidence-based arguments (VCSIS140)

The study of reduction-oxidation (redox) reactions is a standard part of the curriculum at year 9 and/or year 10. Usually the redox laboratory learning activity (LLA) is very prescriptive. In this LLA, students are guided to formulate an inquiry question and to plan an investigation.

Possible inquiry questions include:

An incomplete list!

- What is the minimum concentration of salt (in demineralised water) that could initiate corrosion of a metal?
- Is corrosion more pronounced in salty water? Is there a link between the concentration of salt and the extent of corrosion?
- Are some metals corroded more easily? Are some more resistant to corrosion?

Additional inquiry questions for extension investigations

Possible inquiry questions include:

An incomplete list!

- Is corrosion more pronounced in carbonated water?
- Is corrosion more pronounced in acidic water?
- What is the minimum concentration of salt (in carbonated mineral water) that could initiate corrosion of a metal?
- Is corrosion more pronounced in hotter water? Is there a link between the temperature and the extent of corrosion?
- What is the effect of a surface coating? (For example, we have found that **J.Burrows Paper Clips** have a protective layer that is effective at minimising corrosion. When this layer is removed by a metal file, the paper clips corrode very easily.)
- What is the effect of acidity on corrosion? Typical major storage reservoirs have slightly basic pH (Footnote [13]). Acid rain is acidic and some environmental waters are very acidic (Footnotes [7,8]). Vinegar and soft drink can be used as a model for acidic environmental waters. Is there more or less corrosion in vinegar and soft drink, compared to the extent of corrosion in demineralised water?
- What is the effect of dissolved gases (oxygen)? (For example, dissolved gases, such as oxygen can be removed from water by heating. Freshly boiled and cooled demineralised water is degassed water.)

---

[13] Melbourne Water (2016). Drinking water quality data. Retrieved 29 July 2017 from https://www.melbournewater.com.au/waterdata/drinkingwaterqualitydata/pages/drinking-water-quality.aspx.

- What are the isolated effects of salt and oxygen on corrosion?

	No salt	With salt
No oxygen	Freshly boiled-then-cooled demineralised water	Salt added to demineralised water. Then degassing by boiling and cooling
With oxygen	Demineralised water	Demineralised water with added salt

Conceptual development

Revision/recall of solute, solvent and solution concepts from Year 7 and Year 8.

Revision/recall of types and reactivity of metals from prior studies of the elements and their position in the periodic table from Year 8.

Representation construction approach

Using a representation construction approach (Tytler, Prain, Hubber and Waldrip 2013) can help. The teacher can encourage the students to represent what is happening as a metal is corroded.

Other representations can include whether students choose tables or graphs of text or other ways to summarise data.

Teaching notes

Calculating percentage mass per volume (%m/v)

$$\text{concentration (\%m/v)} = \frac{\text{mass of dissolved substance (g)}}{\text{volume of solution (mL)}} \times 100\%$$

Example:

$$\text{concentration (\%m/v)} = \frac{18\text{ g}}{100\text{ mL}} \times 100\% = 18\%\ \text{(m/v)}$$

Calculating percentage change in mass

$$\text{Percentage change in mass} = \frac{(\text{final mass}) - (\text{initial mass})}{\text{initial mass}} \times 100\%$$

Example:

$$\text{Percentage change in mass} = \frac{(11.62\text{ g}) - (11.58\text{ g})}{11.58\text{ g}} \times 100\%$$
$$= 0.35\%$$

Demineralised, deionised or distilled water?

Demineralised, deionised and distilled water are very similar, but with subtle differences.

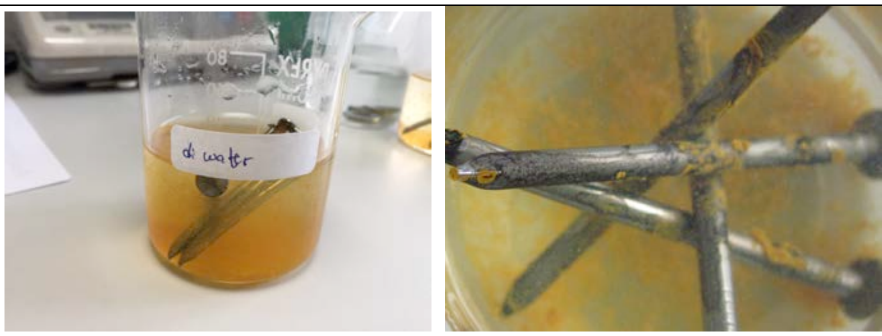
Technically, **distilled water** makes reference to the process (distillation) by which chemically pure water is prepared. Distilled water should have no dissolved ions present. Distillation is an energy-intensive process, which has been mostly replaced by other purification processes.

Deionised water is the name given to chemically pure water in research laboratories. Deionised water should have no dissolved ions present.

Demineralised water is available in supermarkets and other retailers. Demineralised water may have some ions in it, but has very low concentrations of common ions that cause hardness of tap, bore and mineral water.

The results reported in the sample student answers and the teacher notes used **deionised water**. The corrosion that was observed is attributed to the presence of dissolved oxygen since we used (research-grade) deionised water with pH=6.8-7.2.

Rusting of iron



Rusting of **Paslode Bright Nails**, after a few hours.
Photographs: Jessica Saw and Kieran Lim.
Photographs used with permission

The rusting of iron is quite complicated. Under normal conditions iron corrodes to form various insoluble iron(II) hydroxides or green rust. These iron(II) hydroxides can react further to form red-brown "rust" or various hydrated iron(III) oxides. The orangey red corrosion product is FeO.OH, which can then undergo dehydration on drying to form Fe_2O_3. At years 9 and 10, we would expect the following (BBC Bitesize, 2014):

iron (s) + oxygen (g) $\rightarrow$ iron (III) oxide

$4\,Fe\,(s) + 3\,O_2\,(g) \rightarrow 2\,Fe_2O_3\,(s)$

Dissolved salt is an electrolyte. The dissolved ions enable the easy movement of electrical charge in the form of ions from one place to another, thus speeding the electrochemical processes.

The rusting of iron in deionised water was surprising for us as our (university-sourced) deionised water has no ions present. It is believed that the lack of dissolved ions may enable the concentration of dissolved oxygen to be higher so the iron corrodes more extensively.

Weighing and fair testing

An earlier version of this activity suggested that corrosion could be monitored by the change in mass of the solid metal sample(s). Student and teacher results at a workshop showed that mass of the solid metal sample(s) had a small but consistent increase in mass of about 0.010-0.030 g, using the following procedure:

- Dry metal sample(s) weighed
- Metal sample(s) placed in demineralised water, demineralised water plus salt, carbonated water or carbonated water plus salt

- After 15-20 minutes, the metal sample(s) were rinsed in demineralised water, dried using paper towels and reweighed.

Subsequent testing showed that this increase in mass could be observed with less than one minute immersion in liquid. The two weighings follow different procedures. The first weighing is of metal sample(s) that have not been placed in liquid. The second weighing is of metal sample(s) that have been placed in liquid. This is an example of an unfair test that results in a systematic error.

A fair test would require that the first weighing is after a brief (eg 30-second) immersion in demineralised water, followed by rinsing in demineralised water, drying using paper towels and weighing.

Equipment and materials

- Plastic or glass beakers
- Cooking salt
- Plastic spoons or glass stirring rods
- Demineralised water
- Paper clips, hair pins (or 'bobby pins'), metal washers, aluminium foil (1 cm strips), iron nails, galvanised nails, etc.
- Plastic tweezers or tongs
- 100 mL measuring cylinder
- Sticky labels or marker pens
- Safety glasses/goggles and gloves

Optional

- Metal coins
- Stainless steel cutlery
- Additional metal samples
- Carbonated mineral water or soda water
- Soft drink
- Hot water bath
- Thermometer
- Scissors
- Steel wool
- Emery paper or sandpaper
- Electronic balance or scales
- Timer or stopwatch

We have tested **Paslode Bright Nails** from Bunnings (Note [14]). The Paslode website states that bright nails are un-plated, bright iron with no corrosion protective coating, for general interior use where corrosion resistance is of minor importance (Note [15]). We have found that these **Paslode Bright Nails** corrode very easily.

Risk management

- Nails, aluminium foil pieces, emery paper and steel wool may cause cuts and/or lacerations to skin if not handled correctly.
- Water that is used in corrosion experiments may contained dissolved ion, and should not be consumed.
- Use of a kettle to boil water must be situated away from wet areas and must be in good condition (i.e. no frayed chords or exposed wires). There is danger of burns from a hot appliance and/or hot water or steam.

Suggested lesson plan organisation

Lessons 1 and 2: Recall of concepts learned from Years 7 and 8 on solutions, solvents, solutes, concentration, reactivity series of metals and chemical reactions involving formation of rust/corrosion.

% (m/v) - Percentage mass per volume (%m/v) is one method of measuring concentration, defined as the mass of the solute per 100 mL of solution

$$\text{concentration (\%m/v)} = \frac{\text{mass of dissolved substance (g)}}{\text{volume of solution (mL)}} \times 100\%$$

Lesson 3: Plan the inquiry and set up the investigation.

Lesson 4: Check the results of the investigation and analyse the results.

Lessons 5 and 6: Complete presentation of the investigation as a laboratory report, scientific poster, multimedia, or other format.

---

[14] Bunnings (2017). Bunnings Stores <https://www.bunnings.com.au/stores>. Accessed 18 September 2017.

[15] Paslode (2017). Paslode Nails <https://www.paslode.com.au/products/fasteners/104-paslode-nails>. Accessed 18 September 2017.

Suggested classroom organisation of activity

Divide the class into groups of four students. Each group is encouraged to choose two metals each, so that each pair of students work with the same metal.

It is recommended that the inquiry question be finalised in **Lesson 3** and the investigation be set for the reactions to run over until **Lesson 4**, which would be a few hours or days later. This would require somewhere to store the beakers.

This laboratory learning activity is designed as a guided inquiry activity, in which students propose possible inquiry questions. It is not an open inquiry, as the teacher can help refine and finalise the question.

It is recommended that the inquiry be based around the corrosion of metal in demineralised water and saline water (salty water) prepared from demineralised water.

Suggested overall plan:

> Each metal should be tested in a solution without salt (control, blank or reference test) and in one or more solutions with varying concentrations of salt. All solutions could be at room temperature.
>
> Some kind of warm water bath or incubator will be required if students decide to make a test at higher temperature.

Suggested procedure for preparation of solutions (**Lesson 3**):

> To prepare a solution of concentration of 10% m/v of salt in water, weigh 10 g of salt into a dry beaker and fill approximately 80 mL (demineralised) water. Dissolve the salt before topping up with (demineralised) water to the 100 mL mark.

Suggested procedure for preparation of metals (**Lesson 3**):

> Students should be encouraged to make careful observations of the metal(s) before the test.

Fair test

> Even though we found that the changes in mass was miniscule, students might make measurements of the mass at the start of the test. If they do so, each of the metal(s) should be put into (demineralised) water for about 20-30 seconds, removed from water, dried and weighed. **Student discussion: Why is it important to wet each piece of metal before drying and weighing?**

Optional: polish each of the metal(s) with a metal file, emery paper or sandpaper. It has been found that "bright iron" corrodes reliably every time, even straight out of the package.

Suggested procedure for observing corrosion of metals (**Lesson 4**):

Students should be encouraged to make careful observations of the metal(s) at the conclusion of the test.

Once each group has tabulated their results, they should assign a scribe to collect all the results from the other groups to have a larger data set for analysis.

Approximate time indications to complete activity

Lessons 1 and 2: Recall of concepts learned from Years 7 and 8 on solutions, solvents, solutes, concentration, reactivity series of metals and chemical reactions involving formation of rust/corrosion.

Towards the end of **Lesson 2**:

5 minutes	Groups brainstorm possible scientific questions
15 minutes	Class discussion of possible scientific questions and groups select/refine scientific question(s)

Lesson 3:

10 minutes	Introduction and review of safety aspects
15-20 minutes	Setting up of solutions

Lesson 4: Check the results of the investigation and analyse the results.

10-15 minutes	Observing metal samples
15-20 minutes	Sharing and analysing results
10 minutes	Pack-up and clean up. Use a sieve or strainer to collect metals before pouring (salt) solutions into the sink.

Communication

Students could present the outcomes of this inquiry activity as a laboratory report, scientific poster or other multimedia format.

References

ACARA (May 2015). Australian Curriculum Version 7.5 Foundation-10 Science. Australian Curriculum, Assessment and Reporting Authority. Retrieved 16 July 2017 from http://v7-5.australiancurriculum.edu.au/science/curriculum/f-10

Australasian Corrosion Association Inc. (n.d.) ACA Foundation Ltd. Retrieved 16th July 2017 from https://foundation.corrosion.com.au/

Australian Broadcasting Corporation Science (2002). New probe to study rust in 'real-time'. Retrieved 16 July 2017 from http://www.abc.net.au/science/articles/2002/02/20/485323.htm

BBC (2014) Making cars: Rusting. Retrieved 26 September 2017 from http://www.bbc.co.uk/schools/gcsebitesize/science/ocr_gateway/chemical_resources/making_carsrev1.shtml.

Bruck, L.B., Bretz, S.L., & Towns, M. H. (2008) Characterizing the level of inquiry in the undergraduate laboratory. Journal of College Science, 38(1),52-58.

Compound Interest (2016) Lead in the Water –The Flint Water Crisis. Retrieved 17 July 2017 from http://www.compoundchem.com/2016/01/25/flint-water/

Compound Interest (2016) The Chemistry Behind Your Home's Water Supply. Retrieved 17 July 2017 from http://www.compoundchem.com/2016/04/21/water-treatment/

Curtin University (2009) Media Release: Research shows that corrosion costs the local economy. Retrieved 16 July 2017 from http://news.curtin.edu.au/media-releases/research-shows-corrosion-costs-the-local-economy/.

Lim, K. F. (2006). Negative pH does exist. Journal of Chemical Education, 83(10), 1465.

Lim, K. F. (2012). Why students should learn about negative pH. LabTalk, 56 (3), 10-14.

National Association of Corrosion Engineers International (n.d.). I am NACE-Craig Stevenson. Retrieved 16 July 2017 from https://www.nace.org/Membership/I-AM-NACE---Craig-Stevenson/.

National Research Council (2000). Inquiry and the national science education standards: A guide for teaching and learning. Washington DC: National Academic Press.

NOAA (2017). Why is the ocean salty? National Oceanic and Atmospheric Administration, US Department of Commerce. Retrieved 16 July 2017 from https://oceanservice.noaa.gov/facts/whysalty.html.

Murphy, P. (4 January 2003). Chairlift Collapse 18 Hurt. The Age. Retrieved 16 July 2017 from http://www.theage.com.au/articles/2003/01/03/1041566225573.html.

Tullo A.H. (17 September 2007) Foiling corrosion involves outsmarting metals' nature. Chemical and Engineering News, 85(38), p. 20. Retrieved 16 July from http://cen.acs.org/articles/85/i38/Foiling-Corrosion-Involves-Outsmarting-MetalsNature.html.

Tytler, R., Prain, V., Hubber, P., & Waldrip, B. (Eds.). (2013). Constructing representations to learn in science. Springer Science & Business Media.

VCAA (March 2016). Victorian Curriculum Foundation-10 Science. Victorian Curriculum and Assessment Authority. Retrieved 16 July 2017 from http://victoriancurriculum.vcaa.vic.edu.au/science/.

Where Women Work (n.d.). Cynthia Pierre enjoys her work at BP Australia. Retrieved 17 July 2017 from https://www.wherewomenwork.com.au/Career/252/BP-Cynthia-Pierre-engineer-australia

Suggestions:

Suggestions for improvements of these activities should be sent to Linda Lawrie, ACA Foundation, foundation@corrosion.com.au, or Kieran Lim, ASELL for Schools (Victoria), kieran.lim@deakin.edu.au.

Acknowledgements

The contributions of Linda Lawrie, Jessica Saw, and Ian Bentley, to the refinement of this laboratory learning activity are gratefully acknowledged.

- Photographs of corrosion experiments have been used and redistributed by permission of Jessica Saw and Kieran Lim.

Copyright and Creative Commons