ASELL SCHOOLS Advancing Science & Engineering through Laboratory Learning

SAMPLE ANSWERS

Corrosion: All at Sea

Introduction

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

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, must deter or protect against the effects of corrosion

Photo: Dr Ian MacLeod, Heritage Conservation Solutions.
Photograph used with permission

At some locations, marine archaeologists find metal artefacts and shipwrecks with severe corrosion due to the prolonged time spent submerged in the ocean, while at other sites there are artefacts and shipwrecks with almost no corrosion. Why is there a difference in the extent of corrosion?

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

Key ideas

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.

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

Hazards

- 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 ions, 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.

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.

Part A1: Investigation Instructions

You will work in groups of approximately four students. Each group is assigned two metals each, so that each pair of students works with the same metal.

In your groups, design an experiment, using the provided equipment, that will determine if a metal undergoes corrosion.

Suggested procedure for preparation of solutions:

- To prepare a solution of concentration of 5%(m/v) of salt in demineralised water, weigh 5 g of salt into a dry beaker and add approximately 80-90 mL demineralised water. Dissolve the salt before topping up with demineralised water to the 100-mL mark.
- This procedure can be adapted to make solutions with other concentrations of salt in demineralised water.
- This procedure can be adapted to make solutions with other concentrations of salt in other types of water.

Part A2: Scientific questions

Suggest one or two scientific questions that you could ask using your experimental equipment and materials:

Possible scientific questions include:

- How can corrosion be detected?
- How can a fair test be ensured?
- Are some metals corroded more easily? Are some more resistant to corrosion?
- Is corrosion more pronounced in hotter water?
- Is corrosion more pronounced in salty water?
- Is corrosion more pronounced in different types of water? Carbonated water? Soft drink? Tank water? Bore water?

Some scientific questions will be more suitable for investigation in a classroom setting. Your teacher will lead a discussion to decide which scientific questions will be investigated. Your group will then decide how to investigate that question.

The scientific question that my group will investigate is:

NOTE TO TEACHERS: Depending on the metal, it is possible to visually observe the effect of corrosion over a few hours. It is recommended that Lessons 3 and 4 are **not** a double period.

Possible scientific questions include:

- Are some metals corroded more easily? Are some more resistant to corrosion?
- Is corrosion more pronounced in salty water?

Our hypothesis is:

Our **independent variable** is:

This depends on the scientific question. For each test, possible independent variables include salt content, time of exposure to water, temperature, the ratio of the exposed surface area of the metal to its volume (or mass), etc.

Our **dependent variable** is:

The obvious observable (dependent) variable is the extent of corrosion.

(At years 9 and 10, there is no easy method of quantifying the extent of corrosion.)

Our **controlled variables** are:

Controlled variables are the variables that are kept fixed. Controlled variables include the size and shape of the metal pieces. Any ***possible*** independent variable that is ***not*** varied is a controlled variable.

We will use the following **experimental procedure**. (If appropriate, make a drawing of your proposal.)

A ***possible*** experimental procedure is:

- Prepare a control consisting of a beaker of demineralised water.
- Prepare a set of beakers with conditions that vary one or more independent variables. Controlled variables include the size and shape of the metal pieces. Any ***possible*** independent variable that is ***not*** varied is a controlled variable.
- For example, to make a salt solution of 10% m/v of salt in water, weigh 10 g of salt into a dry beaker and fill approximately 80 mL water. Dissolve the salt, then fill to 100 mL with mark.
- **Most students will not have this next step**. Rub the metal samples with a metal file, sandpaper or similar abrasive surface/material. **What does this achieve?**
- Place the metal sample(s) into the various water samples.
- Wait an appropriate time interval. It is suggested that a time interval of 1-2 days between lessons 3 and 4 is good.

An earlier version of this laboratory learning activity incorrectly suggested that it might be possible to use the mass of the solid to monitor the extent of corrosion. Further tests have found that the change in mass is insignificant.

Are there any **safety** issues to consider?

- 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 ions, 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.

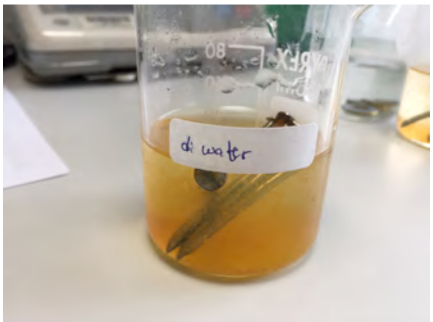
Part A3: Testing our scientific question

Get approval from your teacher of your plans (Part A2) before starting Part A3.

Remember to take photos throughout your experiment to add to your scientific poster.

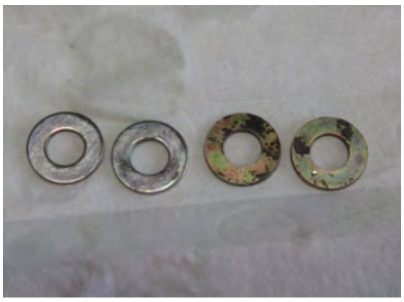
What happened? Record your observations or measurements:

Tests using **Paslode Bright Nails** from Bunnings had easily observable corrosion after a few hours, even with deionised or demineralised water. The water turns an orangey colour that is characteristic of rust (iron oxide) and orange flecks are visible on the surface of the nails.



Tests using **Pinnacle "yellow zinc" washers** with deionised or demineralised water produced small bubbles of gas on the surface of the washers. There were visible changes to these washers.

There was less visible change to washers which had most of the "yellow zinc" coating removed by the use of a metal file before the test (two left-hand-most washers).



Once all the groups have summarised their observations or measurements, a 'scribe' to collect all the results from each of the groups so that you can collate a summary of the entire class's results.

Part B: Analysis of results

Part C: Drawing conclusions (discussion prompts)

What was the purpose of using demineralised water instead of tap water in this experiment?

Demineralised water has very low concentrations of common ions that cause hardness of tap, bore and mineral water. Any corrosion that occurs in demineralised water, indicates that this corrosion is not due to ions like Mg^{2+} or Ca^{2+}, that are commonly found in bore water and other "hard" waters, and also not due to Cl^{-}, that is commonly found in tap water in many towns.

Looking at your results, which metals were the most reactive to the corrosive environment(s) simulated in this activity?

Of the commonly available metals, aluminium, zinc and iron are the most reactive. The corrosion of iron is the easiest to see as there is a very obvious colour change.

Looking at your results, which metals were the least reactive to the corrosive environment(s) simulated in this activity?

Most metals are resistant to corrosion because shops and suppliers usually sell alloys and metals with surface coatings, both of which are designed to minimise corrosion. Coins, copper, alloy (eg stainless steel) are generally resistant to corrosion.

Was this a **fair test**? Are there variables that you have not controlled in your experiment? How might these variables affect your conclusions?

Using the internet, learn about the chemical composition (makeup) of some of the metals that you have used in this activity.

The Paslode website states that bright nails are un-plated, bright iron with no corrosion protective coating <https://www.paslode.com.au/products/fasteners/104-paslode-nails>.

Using internet or textbook resources, write a **word equation** for the reaction of one of the metals that you tested from this activity.

iron (s) + oxygen (g) → iron (III) oxide

BBC Bitesize (2014) <http://www.bbc.co.uk/schools/gcsebitesize/science/ocr_gateway/chemical_resources/making_carsrev1.shtml>

Using internet or textbook resources, write a **chemical equation**, described by the above word equation.

The actual rusting process is quite complicated and involves several steps and with several iron species. The iron species can have different forms, depending on the amount of water that is present.

At year 10 level, the overall equation given below is acceptable.

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

Part D: Extension 1

The ocean is not the only corrosive environment. Use the internet or a library to research other types of corrosive environments and the types of corrosion that can occur within them.

Corrosion depends on three factors:

- A metal that can be corroded (oxidised)
- Moisture (to help the movement of ions/electrolytes during the corrosion process)
- Presence of oxygen of some other oxidising agent.

Non-marine environments that have these factors include:

- Sea-side environment (on land but with lots of sea spray)
- In a garden with lots of rain
- Areas that use salt to de-ice roads (rarely used in Australia)

Use the internet or a library to research materials or methods used to prevent corrosion and suggest which one(s) are suitable for the environment(s) that you have described above.

Materials or methods used to prevent corrosion include:

- **Alloys** like stainless steel (mainly iron, but with small amounts of carbon and about 18% chromium)
- Surface coatings like **paint**
- Surface coatings/treatments like **galvanisation**, which is a layer of zinc (which forms a protective layer of zinc oxide)
- Using a **sacrificial anode**, which attaches a piece of easily-corroded metal to the piece of metal being protected. The **sacrificial anode** is corroded in preference to the piece of metal being protected.

In January 2003, the famous chairlift at Arthur's Seat, on the Mornington Peninsula (south of Melbourne) collapsed, injuring passengers and leaving some stranded for several hours (see footnote 2).

Use the internet or a library to research the answers to the following questions:

- What type of corrosion was blamed for this near-disaster?
- How does this type of corrosion occur?
- What types of personnel were involved in the investigation and management of this accident?
- What human factors were involved in the incident?
- How could these factors have been managed?
- What economic costs occurred as a result of the accident?

Part E1: Extension 2 - Instructions

Consult with your teacher if you should do this second extension.

Based on your results and the class results, can you propose some additional tests relating to the corrosion of metals? To better compare your results from this Part with your earlier investigations, it is suggested that you have similar hypotheses and experimental procedures.

[2] The Age (2003). 'Chairlift Collapse 18 Hurt' Retrieved 16th July 2017 from <http://www.theage.com.au/articles/2003/01/03/1041566225573.html>.

Part E2: Extension 2 - Scientific questions

Our hypothesis is:

A ***possible*** hypothesis is that the presence of dissolved carbon dioxide will displace oxygen, and that the absence of oxygen is expected to decrease the extent of corrosion compared to demineralised water.

Our **independent variable** is:

This depends on the scientific question. For each test, possible independent variables include salt content, temperature, the ratio of the exposed surface area of the metal to its volume (or mass), etc.

Our **dependent variable** is:

Again, it is suggested that the extent of corrosion be monitored visually.

Our **controlled variables** are:

Controlled variables are the variables that are kept fixed. Controlled variables include the size and shape of the metal pieces. Any ***possible*** independent variable that is ***not*** varied is a controlled variable.

We will use the following **experimental procedure**. (If appropriate, make a drawing of your proposal.)

Ideally this procedure should be very similar as the procedure with demineralised water, so that the tests for the two types of water can be compared. However, some students might think of ways to improve their procedure, and hence the procedure here might be different from the procedure with demineralised water.

Are there any **safety** issues to consider?

These should be similar to safety issues for the tests with demineralised water.

Part E3: Extension 2 - Testing our scientific question

Remember to take photos throughout your experiment to add to your scientific poster.

What happened? Record your observations or measurements:

There were no significant differences between the tests using carbonated water and demineralised water.

Once all the groups have summarised their observations or measurements, a 'scribe' to collect all the results from each of the groups so that you can collate a summary of the entire class's results.

Part E4: Extension 2 - Analysis of results

Part F: Scientific poster

5. Complete introduction:

    - One- to two-paragraph overview of the reason for completing the investigation, the scientific context and an explanation of the relevant scientific theory.

    - All sources need to be acknowledged.

6. Complete the discussion section:

    - Discuss your scientific question in this section. **POE** is often a useful guide is to help what you put in this section:

        a. Predict. Your scientific question, hypothesis and prediction of what will happen.

        b. Observe. What you observed or measured.

        c. Explain. Did your observations or measurements agree with your expectations and prediction? Can you explain why?

    - Discuss the implications of your results.

- Were there any limitations to your investigation?

7. Complete the conclusion section:

    - State your main result from your investigation.
    - State whether this supports or refutes your hypothesis.

8. Complete References and Acknowledgements.

Acknowledgements

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- Photograph of shipwreck has been used and redistributed by permission of Dr Ian MacLeod, Heritage Conservation Solutions.
- Photographs of corrosion experiments have been used and redistributed by permission of Jessica Saw and Kieran Lim.

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