

Shipwrecks, Corrosion and Conservation

1. The chemical composition of the ocean implies its potential role as an electrolyte.

1.1 Identify the origins of the minerals in oceans as:

- leaching by rainwater from terrestrial environments
- hydrothermal vents in mid-ocean ridges.

1.1.1 Identify the main anions and cations found in the ocean.

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1.1.2 Complete the following table:

Word	Meaning
Mineral	
Leaching	
Terrestrial	
Hydrothermal vent	
Mid-ocean ridge	

1.1.3 Describe how minerals can be leached from soil and rocks and carried to the ocean.

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1.1.4 Describe how minerals can enter the ocean from hydrothermal vents.

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1.2 Outline the role of electron transfer in oxidation-reduction reactions.

1.2.1 Compare the terms oxidation and reduction.

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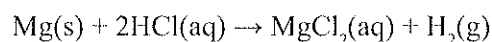
- 1.2.2** Explain in terms of transfer of electrons how oxidation and reduction must go together. Include an example.

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- 1.2.3** Use half equations to show that the following redox reaction is an electron transfer reaction.



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1.3 Identify that oxidation-reduction reactions can occur when ions are free to move in liquid electrolytes.

1.3.1

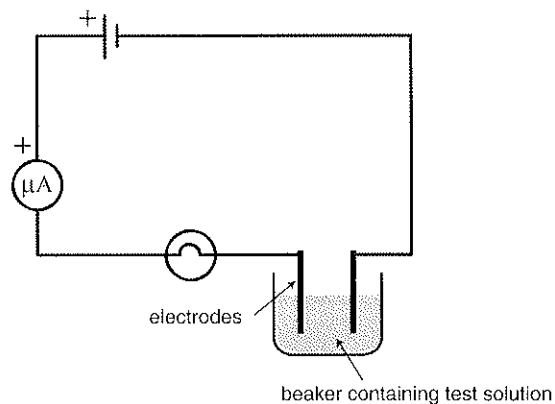
- (a) Define electrolyte and give examples.

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- (b) The diagram opposite shows an electric circuit used to test the ability of solutions to conduct electricity. Suggest observations you could expect to make if the test solution is:



- (i) fresh water

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- (ii) ocean water

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- 1.3.2** Outline how redox reactions can occur in electrolytes.

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1.4 Process information from secondary sources to outline and analyse the impact of the work of Galvani, Volta, Davy and Faraday in understanding electron transfer reactions.

1.4.1 Luigi Galvani was an 18th century Italian scientist. Outline the work of Galvani.

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1.4.2 Alessandro Volta was a contemporary of Galvani, in Italy at the same period. Outline Volta's contribution to electron transfer reactions.

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1.4.3 Humphry Davy was an English scientist during the late 18th and early 19th centuries. Outline Davy's contribution to electrochemistry.

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1.4.4 Michael Faraday was a 19th century English scientist. Briefly describe Faraday's contribution to electrochemistry.

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1.4.5 Analyse the impact of the work of these four scientists on our understanding of electron transfer reactions.

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1.5 Describe the work of Galvani, Volta, Davy and Faraday in increasing understanding of electron transfer reactions.

1.5.1 Complete the following table to describe how each of these scientists increased our understanding of electron transfer reactions.

Name	Significance of work in electrochemistry
Luigi Galvani	
Alessandro Volta	
Humphry Davy	
Michael Faraday	

2. Ships have been made of metals or alloys of metals.

2.1 Describe the conditions under which rusting of iron occurs and explain the process of rusting.

2.1.1 Define rusting and describe the appearance of rust.

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2.1.2 Outline the conditions necessary for rusting to occur.

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2.1.3

(a) Describe the anode reaction in rusting. Include an equation.

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(b) Describe the cathode reaction in rusting. Include an equation.

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(c) Construct the overall equation leading to the formation of iron(II) hydroxide and outline any further oxidation that occurs.

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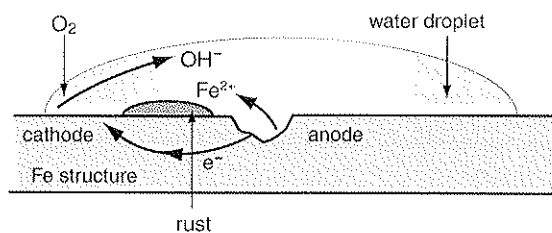
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(d) State the formula of rust.

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- 2.1.4** The diagram opposite shows a piece of iron going rusty. Using this diagram as a model, explain the process of rusting and comment on any limitations of this model.



- 2.2** Use available evidence to analyse and explain the conditions under which rusting occurs.

- 2.2.1** Describe the role of water in rusting.

- 2.2.2** Explain the need for oxygen in rusting.

- 2.2.3** Explain the effect of pH on rusting.

- 2.2.4** Analyse the relationship between temperature and rusting.

2.2.5 The presence of other elements either as impurities or alloyed into iron affects the rate of rusting. Analyse the effects of other elements on rusting, including examples.

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2.2.6 A group of students decide to test the hypothesis that iron rusts faster in the presence of salt water than fresh water. They select two identical, clean nails and place one in each of the following test tubes:

Test tube A contains 10 mL salt water

Test tube B contains 10 mL fresh water

They observe the nails each day for a week.

- (a) Identify the independent variable, the dependent variable and the controlled variables in their experiment.

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- (b) Outline the expected results.

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- (c) The teacher questions the reliability of the students' results. Outline how they could improve their experimental design to obtain more reliable results.

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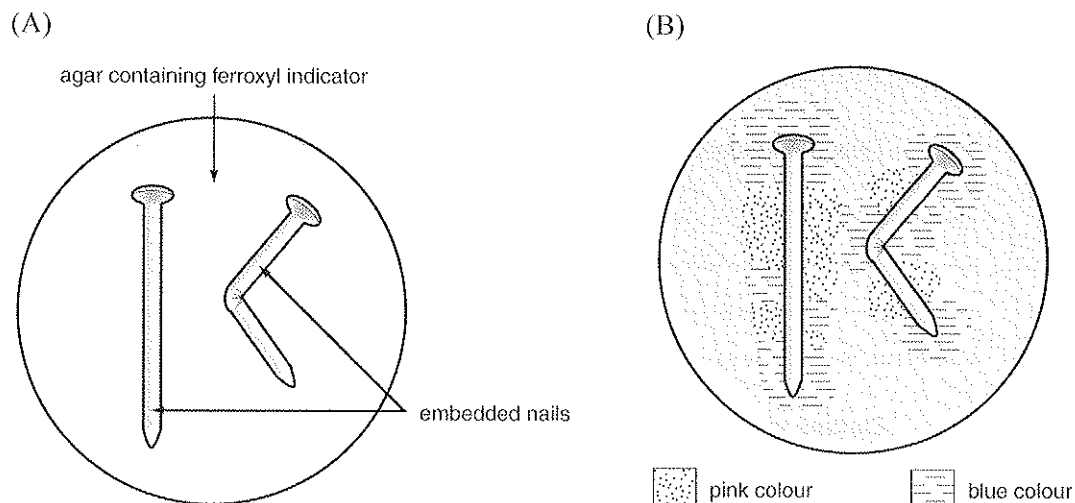
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- (d) Another student suggests that the nails might have rusted without either salt or fresh water present. Outline how the students could be sure that water was needed for the rusting of iron.

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- 2.2.7 The diagram (A) below shows an agar plate in which two nails are embedded, one straight and the other bent. The agar contains indicators which turn blue when oxidation of iron occurs (indicating an anode) and pink when reduction of iron occurs (indicating a cathode). Diagram (B) shows the same agar plate after standing for one week.



- (a) Identify two valid conclusions that can be drawn from the results shown.
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- (b) One of the indicators mixed in with the agar is phenolphthalein. Explain why a deep pink colour is produced at the cathodes.
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- (c) The agar also contains a solution of potassium ferricyanide that turns blue in the presence of Fe^{2+} ions. Explain the formation of a blue colour at the anodes.
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2.3 Identify data, select equipment, plan and perform a first-hand investigation to compare the rate of corrosion of iron and an identified form of steel.

2.3.1 Define corrosion.

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2.3.2

- (a) You carried out a first-hand investigation to compare the rate of corrosion of iron and an identified form of steel. Identify the iron and steel samples you used for your investigation, including their composition.

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- (b) Describe the conditions used in your experiment to compare corrosion in iron and steel.

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- (c) Outline your results.

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- (d) Explain your results.

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- (e) Evaluate the reliability of your results.

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2.4 Identify the composition of steel and explain how the percentage composition of steel can determine its properties.

2.4.1

- (a) Identify the composition of steel.

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- (b) Different types of steel can be made for a variety of purposes. Explain.

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2.4.2

- (a) Discuss the effect on the properties of steel of lowering the carbon content.

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- (b) Identify a use of:

- (i) low carbon steel

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- (ii) high carbon steel

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- 2.4.3** Using stainless steel as an example, explain how the composition of steel can determine its properties.

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2.5 Gather and process information from secondary sources to compare the composition, properties and uses of a range of steels.

2.5.1 Use the following scaffold to tabulate gathered information showing the composition, properties and uses of at least four different steels.

Composition	Properties	Uses

2.5.2 Explain the ability of stainless steel to resist corrosion.

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2.6 Identify iron and steel as the main metals used in ships.

2.6.1 Identify the main metal used for the hulls of ships.

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2.6.2 Identify properties of steel which make it suitable for ship's hulls.

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2.6.3 Suggest uses of cast iron in ships.

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2.7 Account for the differences in corrosion of active and passivating metals.

2.7.1

- (a) Distinguish between active and passivating metals, including differences in their tendency to corrode. In your answer, include examples.

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- (b) Account for these differences in corrosion.

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3. Electrolytic cells involve oxidation-reduction reactions.

3.1 Describe, using half equations, what happens at the anode and cathode during electrolysis of selected aqueous solutions.

3.1.1 Define electrolysis.

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3.1.2

- (a) Draw a fully labelled diagram to show the electrolysis of water, including labelling the products formed.

- (b) Construct an overall equation for this decomposition reaction, then show anode and cathode half equations.

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3.1.3 Describe a typical electrolytic cell.

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3.1.4 During electrolysis, explain what happens at the:

- (a) anode

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- (b) cathode

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3.1.5

- (a) Draw a labelled electrolytic cell to show electrolysis of dilute sodium chloride, using inert electrodes.

- (b) Identify the products of electrolysis of:

(i) dilute sodium chloride

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(ii) concentrated sodium chloride (brine)

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- (c) Analyse the changes to the products when the concentration of the sodium chloride solution is increased and other factors are kept constant.

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3.1.6 Identify some uses of electrolysis.

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3.1.7

- (a) Draw an electrolytic cell to show the electroplating of an object with copper.

- (b) Construct half equations for the anode and cathode of this cell.

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3.1.8

- (a) Draw an electrolytic cell suitable for cleaning a corroded, silver spoon coated with black silver sulfide from a shipwreck.

- (b) Describe, using equations, how the cutlery surface would be cleaned.

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- 3.19** Explain how you could determine the anode reaction that would occur in an electrolytic cell with an aqueous electrolyte and a copper anode.

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3.2 Describe factors that affect an electrolysis reaction:

- effect of concentration
- nature of electrolyte
- nature of electrodes.

3.2.1 Describe how the concentration of the electrolyte in an electrolytic cell can affect the:

(a) products obtained

(b) rate of reaction

3.2.2 Describe how the nature of the electrolyte affects an electrolysis reaction.

3.2.3 Discuss the importance to an electrolysis reaction of:

(a) size of the electrodes

(b) placement of the electrodes

(c) composition of the electrodes

3.3 Plan and perform a first-hand investigation and gather first-hand data to identify the factors that affect the rate of an electrolysis reaction.

3.3.1 During this course you planned and performed a first-hand investigation to identify the factors that affect the rate of an electrolysis reaction.

(a) Identify the factors that you investigated in your experiment.

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(b) Describe the cell that you used in your investigation.

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3.3.2

(a) Outline the procedure you used to investigate one named factor that you studied.

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(b) Identify the dependent variable and describe how you measured it.

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(c) Write a conclusion for your experiment.

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- 3.3.3** A group of students plan to investigate the effect of a number of factors on the rate of electrolysis of aqueous copper sulfate. This reaction leads to the decomposition of copper sulfate and the deposition of copper at the cathode. The factors to be investigated are listed in the table below.

Based on your experiences of electrolysis, write an hypothesis suitable for investigating the effect of each of these factors.

Factor investigated	Hypothesis
Varying electrolyte concentration	
Varying voltage	
Varying area of electrode immersed	
Varying the distance apart of the electrodes	

4. Iron and steel corrode quickly in a marine environment and must be protected.

4.1 Identify data, gather and process information from first-hand or secondary sources to trace historical developments in the choice of materials used in the construction of ocean-going vessels with a focus on the metals used.

4.1.1 Construct a timeline to summarise the historical developments in the use of materials for ships.

4.1.2 Justify the use of iron for ship construction during the early 19th century.

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4.1.3 Explain how improvements in technology have impacted on the materials used in the construction of ships.

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- 4.2 Identify data, choose equipment, plan and perform a first-hand investigation to compare the corrosion rate, in a suitable electrolyte, of a variety of metals, including named modern alloys to identify those best suited for use in marine vessels.**

4.2.1

- (a) Describe the experiment you carried out to compare the corrosion rate of a variety of metals and alloys and identify those best suited for use in marine vessels.

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- (b) Outline the results you obtained.

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- 4.2.2 Explain why corrosion occurs more rapidly in a marine environment.**

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- 4.3 Identify the ways in which a metal hull may be protected including:**

- corrosion resistant metals
- development of surface alloys
- new paints.

- 4.3.1 Justify the need for corrosion protection in hulls of ships.**

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4.3.2 Explain, using examples, how steel can be made more corrosion resistant by alloying.

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4.3.3 Outline the development of surface alloying of steel.

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4.3.4

(a) Paints and coatings have long been used for corrosion protection of steels. Explain how they provide protection.

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(b) List some advantages and disadvantages of using paints for corrosion protection in ships.

Advantages	Disadvantages

4.3.5 Discuss the new developments in paints suitable for marine environments.

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4.4 Plan and perform a first-hand investigation to compare the effectiveness of different protections used to coat a metal such as iron and prevent corrosion.

4.4.1

- (a) Describe the method and materials you used to carry out this experiment.

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- (b) Comment on the validity of your experiment.

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4.4.2 Assess the effectiveness in corrosion protection of the materials used.

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4.4.3 Predict the degree of protection provided if iron samples are coated by dipping them in:

- (a) molten zinc

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- (b) molten tin

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4.4.4 An experiment was performed to test the effectiveness of paint coatings A, B and C on steel. The paints were each applied in a thin, even layer over the steel samples. Some samples of each paint were shaken in a container with stones before all the samples were left in sea water for a month.

(a) Identify a suitable control for this experiment.

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(b) Identify all the variables that should be controlled for this to be a valid test.

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(c) On the basis of the results it was decided that paint A provided the best protection against corrosion. Outline observations that would have led to this conclusion.

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4.5 Predict the metal which corrodes when two metals form an electrochemical cell using a list of standard potentials.

4.5.1 For the following pairs of metals, using the standard potentials listed in the data table at the back of this book, predict which metal in each pair will corrode when they are together in a galvanic cell. Complete the table.

Metals	Standard potentials from table	Metal which will corrode
Mg, Fe		
Zn, Ag		
Sn, Fe		
Cu, Zn		

4.5.2 Identify the general rule for determining the metal which will oxidise (corrode) when two metals are in contact.

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4.5.3 Explain how electrochemical cells can be formed in ships.

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4.6 Outline the process of cathodic protection, describing examples of its use in both marine and wet terrestrial environments.

4.6.1 Define cathodic protection.

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4.6.2 When cathode protection is being used, describe the process taking place at each electrode. Include equations in your answer.

(a) cathode:

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(b) anode:

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4.6.3

(a) Identify marine and wet terrestrial situations in which cathodic protection is used.

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(b) Construct a table to summarise advantages and disadvantages of cathodic protection in the marine environment.

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- (c) Construct a table to compare cathodic protection to the use of paints to protect the hulls of ships.

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4.7 Describe the process of cathodic protection in selected examples in terms of the oxidation/reduction chemistry involved.

4.7.1

- (a) Describe the sacrificial anode method of cathodic protection.

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- (b) Discuss the chemistry of the sacrificial anode method.

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4.7.2

- (a) Outline how an impressed current system works.

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- (b) Discuss the chemistry of the impressed current system.

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- 4.7.3** The use of sacrificial anodes and impressed current are two methods of cathodic protection. Compare these two methods.

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- 4.7.4** Under certain conditions, galvanised iron can be considered a method of cathodic protection. Explain.

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4.8 Gather and process information to identify applications of cathodic protection, and use available evidence to identify the reasons for their use and the chemistry involved.

4.8.1

- (a) Identify examples of the use of both sacrificial anodes and impressed currents.

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- (b) For each of these uses, identify reasons for the use and outline the chemistry involved.

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5. When a ship sinks, the rate of decay and corrosion may be dependent on the final depth of the wreck.

5.1 Outline the effect, on the solubility of gases and salts, of:

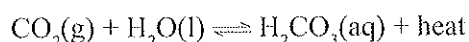
- temperature
- pressure.

5.1.1 Identify the change in solubility of gases as temperature rises.

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5.1.2 Using the following equilibrium, explain the effect of temperature on solubility of carbon dioxide gas.



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5.1.3 Identify the trend in solubility of salts with increasing temperature.

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5.1.4 At 0°C 35.7 g NaCl / 100 mL gives a saturated solution, whereas at 20°C 36.0 g NaCl in 100 mL is needed to produce a saturated solution. Discuss the solubility of sodium chloride at different temperatures.

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5.1.5 Outline the effects of pressure on the solubility of both gases and salts.

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5.2 Identify that gases are normally dissolved in the oceans and compare their concentrations in the oceans to their concentrations in the atmosphere.

5.2.1 Identify how gases enter the ocean waters.

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5.2.2 Identify how gases reach the lower depths of the ocean.

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5.2.3 Complete the following table to compare concentrations of oxygen, nitrogen and carbon dioxide in the atmosphere and dissolved in the water of the ocean.

Gas	Concentration in the atmosphere	Concentration in the ocean
Oxygen		
Nitrogen		
Carbon dioxide		

5.3 Compare and explain the solubility of selected gases at increasing depths in the oceans.

5.3.1

(a) Identify changes in temperature with increasing depth of the ocean.

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(b) Identify the changes in pressure with increasing depth.

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5.3.2 Identify and explain the changes in oxygen concentration with increasing depth.

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5.3.3 Compare the solubility of nitrogen in the ocean with that of oxygen.

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(a) Compare the solubility of carbon dioxide in the ocean with that of oxygen.

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(b) Explain why carbonate and hydrogen carbonate ions are common in sea water.

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5.4 Predict the effect of low temperatures at great depths on the rate of corrosion of a metal.

5.4.1 Predict the effect of temperatures at great depths on reaction rate.

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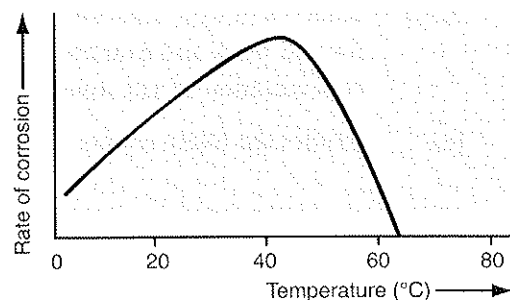
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5.4.2 Predict the effect of temperature on corrosion of metals at great depth.

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5.4.3 The graph opposite shows the effect of water temperature on the rate of corrosion of steel in salt water. Explain the trend in this graph.



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5.5 Perform a first-hand investigation to compare and describe the rate of corrosion of materials in different:

- oxygen concentrations
- temperatures
- salt concentrations.

5.5.1 Samples of copper, iron and steel were placed into identical salt solutions containing differing levels of oxygen. These solutions were prepared as follows:

A – boiling the solutions for a time, then cooling in a sealed container to lower oxygen content

B – aerating with a fish tank filter to produce a solution saturated with oxygen

C – leaving a solution open in contact with air

The samples were examined for signs of corrosion after one week.

(a) Predict and explain the likely results.

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(b) Identify the control.

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(c) Identify the variables that need to be controlled for this to be a valid investigation.

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5.5.2 Samples of iron, steel and copper were placed in salt solutions of varying concentration for one week and examined for corrosion. The aim was to test for the effect of varying the concentration of salt solutions.

(a) Predict the likely results.

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(b) Identify a suitable control for this experiment.

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(c) Identify the variables that need to be controlled for this to be a valid investigation.

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5.5.3 Write a procedure that will test the same metals for the effects of temperature on corrosion.

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5.6 Use available evidence to predict the rate of corrosion of a metal wreck at great depths in the oceans and give reasons for the prediction made.

5.6.1 Identify the conditions of temperature, pressure, light, salt concentration and oxygen concentration that you would expect to find at great depths.

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5.6.2 Predict the rate of corrosion of a metal wreck at great depths. Justify your prediction.

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6. Predictions of slow corrosion at great depths were apparently incorrect.

6.1 Perform a first-hand investigation to compare and describe the rate of corrosion of metals in different acidic and neutral solutions.

6.1.1

- (a) Describe the experiment you carried out to investigate the corrosion of different metals in acidic and neutral solutions. Identify the metals you used and the acid and neutral solutions used.

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- (b) Identify the hypothesis you tested in your experiment.

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- (c) Assess the validity of your experimental procedure.

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- (d) Write a conclusion based on your experimental results.

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6.1.2 A student placed identical pieces of iron into test tubes containing solutions that varied in acidity. The solutions she used were $0.1 \text{ mol L}^{-1} \text{ HCl}$, $0.01 \text{ mol L}^{-1} \text{ HCl}$, $0.001 \text{ mol L}^{-1} \text{ HCl}$ and tap water. After one week, she observed the iron for any signs of corrosion.

(a) Identify the pH of the solutions this student used.

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(b) The student's hypothesis was: Corrosion of iron is faster in solutions with higher pH.

Based on your experiences of corrosion in the laboratory, indicate whether or not you would expect the results to support her hypothesis.

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(c) The student reported that there was no rust in the test tubes containing acid, however there was rust in the test tube containing water. The teacher suggested that the student also look for other signs of corrosion. Explain these results and suggest other observations that could indicate corrosion.

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6.2 Explain that acidic environments accelerate corrosion in non-passivating metals.

6.2.1 Describe how a passivating metal is protected from corrosion.

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6.2.2 Including equations, explain how corrosion in a non-passivating metal such as iron is accelerated in an acidic environment.

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6.2.3 Identify whether sea water is acidic or basic.

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6.3 Explain that shipwrecks at great depths are corroded by electrochemical reactions and by anaerobic bacteria.

6.3.1 Account for the presence of anaerobic bacteria at great depths in the ocean.

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6.3.2 Assess the role of electrochemical cells and anaerobic bacteria in corrosion of shipwrecks at great depths.

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6.4 Describe the action of sulfate-reducing bacteria around deep wrecks.

6.4.1 Anaerobic bacteria utilise sulfate ions from sea water instead of oxygen for respiration. The sulfate ions are reacted to sulfur atoms and then sulfide ions. Using oxidation numbers, demonstrate that this is reduction.

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6.4.2 Part of the respiratory process in sulfate-reducing bacteria involved the reduction of sulfate ions. Construct an equation to show the reduction of sulfate ions to form hydrogen sulfide and water by anaerobic bacteria.

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6.4.3

(a) Describe, including equations, how the iron in shipwrecks could possibly react with the hydrogen sulfide, produced by anaerobic bacteria, and with water to produce an acid environment and iron hydroxide.

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(b) Describe the effect of the acid microenvironment on corrosion.

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(c) Outline how the above reactions can account for the observations of corrosion found at the site of the shipwrecks at depth.

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6.4.4 In 1912 an ocean liner, the *Titanic*, hit an iceberg and sank in water approximately 4 km deep. It was predicted that the *Titanic* would show little corrosion because of the depth to which it had settled in the ocean. However, when the *Titanic* was discovered in 1985, it was found to be severely corroded. Account for the predictions made and outline the importance of the discovery of the *Titanic* to our understanding of corrosion at depth.

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7. Salvage, conservation and restoration of objects from wrecks requires careful planning and understanding of the behaviour of chemicals.

7.1 Explain that artefacts from long submerged wrecks will be saturated with dissolved chlorides and sulfates.

7.1.1 Define artefacts and provide some examples.

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7.1.2 Explain how submerged objects become saturated with chlorides and sulfates.

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7.2 Describe the processes that occur when a saturated solution evaporates and relate this to the potential damage to drying artefacts.

7.2.1 Describe what happens when a saturated solution evaporates.

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7.2.2

(a) Describe what happens to an artefact, with salts impregnated in its structure, if it is allowed to dry out.

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(b) Provide some examples of the damage that could be caused to different types of artefacts when they are allowed to dry with salts in their structure.

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7.2.3 Describe the actions taken by conservators to avoid damage to an artefact when it is recovered from a wreck.

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7.2.4

- (a) Identify the word used to describe the process of removing salts from artefacts.

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- (b) Outline the method used to monitor the progress of salt removal.

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7.3 Identify the use of electrolysis as a means of removing salt.

- 7.3.1** Describe and draw a labelled diagram of an electrolytic cell suitable for removing deeply embedded salts from metal artefacts.

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- 7.3.2** Construct equations to show anode and cathode reactions in an electrolytic cell for removing salt from artefacts.

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7.4 Identify the use of electrolysis as a means of cleaning and stabilising iron, copper and lead artefacts.

7.4.1 Many artefacts have a black sulfide coating on them when recovered. Describe and draw a labelled diagram of an electrolytic cell that could be used to clean a sulfide coating from a metal artefact.

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7.4.2 If a metal object has formed oxides, hydroxides, chlorides or sulfides in its structure as a result of corrosion, explain how electrolysis can be used to clean and stabilise the objects.

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7.5 Discuss the range of chemical procedures which can be used to clean, preserve and stabilise artefacts from wrecks and, where possible, provide an example of the use of each procedure.

7.5.1 Complete the following table to summarise some chemical procedures used to conserve and preserve artefacts.

Procedure	Outline of method	Example of use
Electrophoresis		Cleans delicate ceramic and organic materials, e.g. banknotes, leather goods.
Hydrogen furnace reduction		Helps to restore the structure of badly corroded iron objects.
Acid baths		Calcium carbonate deposits can be removed from objects such as wood.
Impregnation of wood with polymers		Used to restore strength to wooden objects attacked by micro-organisms which destroy cellulose in the structure.
Apply wax coating or lacquers		Preserve objects from further corrosion for display, e.g. in a museum.

7.6 Perform investigations and gather information from secondary sources to compare conservation and restoration techniques applied in two Australian maritime archaeological projects.

7.6.1 Define the following terms:

(a) maritime archaeology

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(b) conservation

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(c) restoration

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7.6.2 During your course you researched two Australian projects undertaken to conserve and/or restore artefacts recovered from shipwrecks. Use the following table to compare the techniques used by conservators to desalinate, clean, stabilise, possibly restore and preserve the objects in these two projects.

	Project 1	Project 2
Details of project		
Wash, clean		
Desalinate and stabilise		
Possibly restore		
Preserve from further corrosion		

7.6.3 Discuss the importance of maritime archaeology to modern society.

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