

Module 5 ANSWERS.

CHAPTER 20: THE OCEAN ENVIRONMENT**Review exercise 20.1**

- 1 The bonding and intermolecular forces within the solute.
The forces between the solute and water.
The temperature of the water.
- 2 High intermolecular forces between gas molecules and water molecules, resulting in ionisation reactions.

Review exercise 20.2

- 1 As temperature increases, solubility of gas decreases.
As pressure of the gas above water increases, solubility of gas increases.
- 2 $\text{CO}_2(\text{aq}) \leftrightarrow \text{CO}_2(\text{g})$ so when the container is opened, the pressure of $\text{CO}_2(\text{g})$ above the liquid rapidly decreases. The equation shifts to the right-hand side in order to counteract the fall in pressure by producing more $\text{CO}_2(\text{g})$ molecules from the solution (Le Chatelier's principle).
- 3 $[\text{O}_2]$ is greatest near the surface due to atmospheric O_2 and O_2 produced by photosynthetic aquatic organisms. $[\text{O}_2]$ decreases as depth of ocean increases due to use of O_2 in respiration of organisms and their decomposition. At great depths, $[\text{O}_2]$ may increase due to presence of dense, cold water containing high O_2 levels—'global conveyor belt'. $[\text{CO}_2]$ increases with ocean depth. At the surface, CO_2 is used for photosynthesis. With increasing depth and less light penetration, less photosynthesis occurs and more CO_2 is produced due to respiration and decomposition of organisms.

Review exercise 20.3

- 1 The leaching effects of rain water passing through terrestrial environments and hydrothermal vents in mid-ocean ridges.
- 2 Aquatic electric current transfer requires mobile ions and sea water has these.
- 3 No outlet to large sea mass. High evaporation, low precipitation due to regional weather interferes with water cycle.
- 4 Salts of chromium, copper, gold, manganese and nickel are generally insoluble. Superheated water from volcanic mid-ocean ridges readily dissolves these minerals, which become dispersed and form underwater mineral deposits.

Chapter 20 Application and investigation

- 1 KCl —soluble. Ions surrounded by polar water molecules.
 $\text{C}_6\text{H}_{12}\text{O}_6$ —soluble. Polar molecule forms hydrogen bonds with water molecules.

Solutions Manual: Module 5

Shipwrecks, corrosion and conservation

Chemistry
Contexts 2
SECOND EDITION

CO₂—slightly soluble. Reacts with water to form carbonic acid which then partially ionises.

C₂H₆—insoluble. Non-polar solute in polar solvent. Will not react with water.

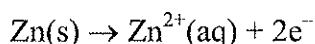
- 2 NH₃, SO₂, O₂ decreasing order of solubility. Decreasing order of reaction with water. NH₃ readily reacts with water forming ammonium and hydroxide ions. SO₂ reacts with water, forming H₂SO₃ which partially ionises. O₂ molecules have only dispersion forces with water molecules.
- 3
 - a Weak dispersion forces between water and O₂ decrease as temperature or average kinetic energy of particles increases. Hence, as temperature increases, solubility of O₂ decreases. Water which has been boiled is depleted of dissolved O₂. After cooling, a goldfish would not survive in this water.
 - b Pressure increases the number of gas molecules per unit volume. This causes an increase in the rate at which the gas enters the solution and so the concentration of dissolved gas increases. Carbonated drinks are bottled at high pressures of carbon dioxide to ensure high concentration of dissolved CO₂ in the liquid.
- 4 Investigation
- 5 Investigation
- 6
 - a Weigh a sample of sea water in a sealed container (*W*₁).
 - b Remove top from container and warm.
 - c To ensure all the gas has escaped from the seawater, replace top securely, shake container and contents. When liquid has settled, remove top. If any further gas appears to be released, repeat **b**.
 - d Replace top, re-weigh bottle (*W*₂).
 - e Mass of dissolved gases = (*W*₁ – *W*₂) g.
- 7 Investigation
- 8 Investigation
- 9 Investigation

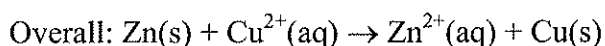
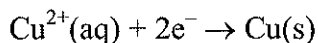
CHAPTER 21: OXIDATION–REDUCTION REACTIONS

Review exercise 21.1

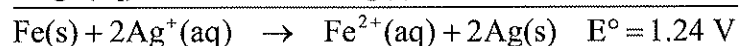
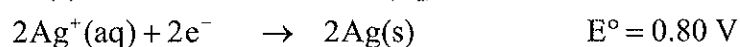
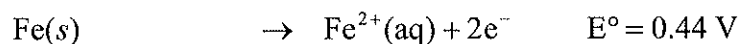
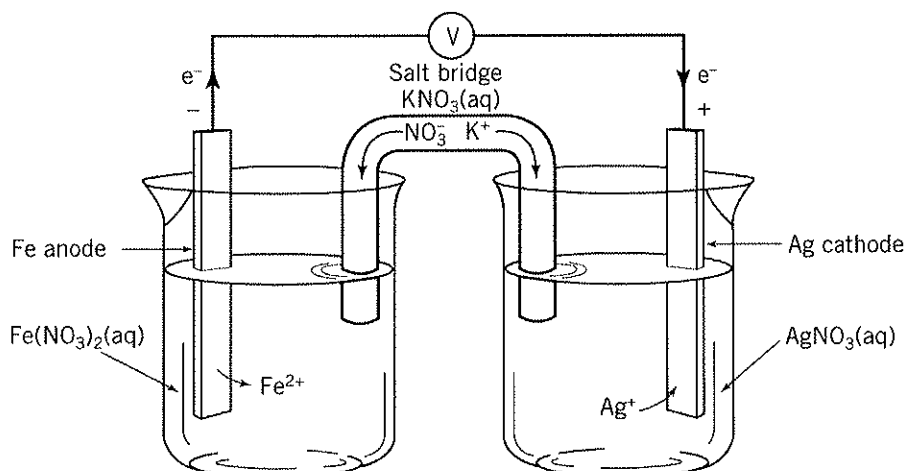
- 1 Oxidation is loss of electrons. Reduction is gain of electrons.

For electron transfer to occur, the two processes must occur simultaneously, e.g. zinc in a solution of copper(II) sulfate will lose electrons (oxidation) to copper(II) ions, which are reduced.





2

3 $\text{Cu}(\text{s}) | \text{Cu}^{2+}(\text{aq}) || \text{Ag}^{+}(\text{aq}) | \text{Ag}(\text{s})$

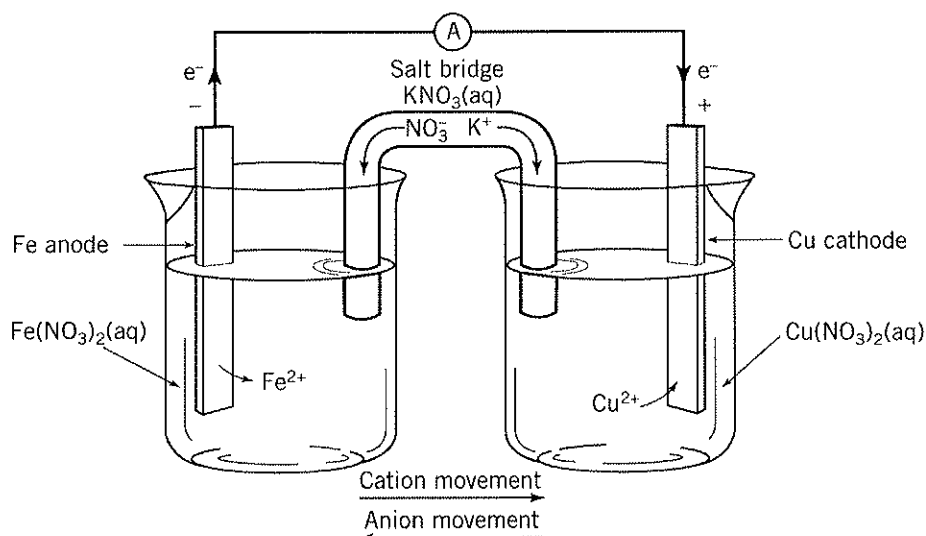
4 Galvanic: Chemical energy is converted to electrical energy. The reaction is spontaneous with a positive voltage.

Electrolytic: Electrical energy is converted to chemical energy. The reaction is not spontaneous and energy must be supplied.

Review exercise 21.2

- 1
 - a Galvani: The muscle contracted due to the passage of an electric current. The muscle had generated the electricity.
Volta: The different metals in a solution generated the electricity, not the muscle.
 - b Volta made the first galvanic cell to produce an electric current.
- 2 Na, K, Mg and Ca are found in nature in compounds which contain their stable ions. Electrolytic techniques enabled electrons to be added to these metal ions and convert them to elements.

2 a, b



3 Investigation

4 Investigation

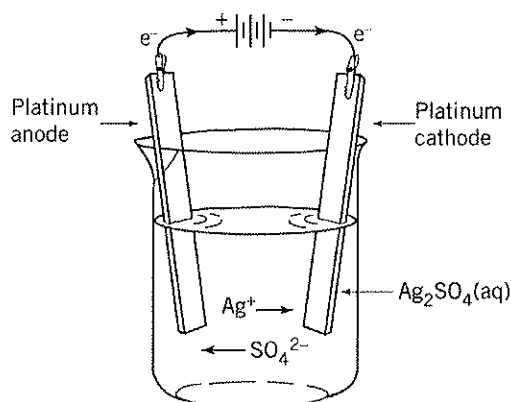
5 Electrons are gained in reduction and lost in oxidation. The number of moles of electrons lost in oxidation equals the number of electrons gained in reduction. The charge on ions is equal in magnitude to exactly one, two, three or four times that of one electron. This corresponds to the transfer of electrons during the formation of ions.

By using the formula $Q = It$ and $n(e^-) = \frac{Q}{9.65 \times 10^4}$, it is possible to work out the number of moles of electrons which flow through a circuit when a given current flows for a fixed time.

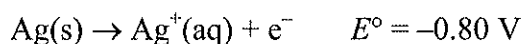
Volumes and masses of products can be calculated, knowing the numbers of electrons involved at each electrode half equation.

6 $\text{CrO}_4^{2-}(\text{aq}) + 8\text{H}^+(\text{aq}) + 6e^- \rightarrow \text{Cr}(\text{s}) + 4\text{H}_2\text{O}(\text{l})$

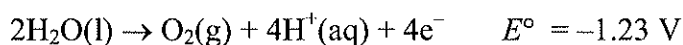
7

Cathode: $\text{Ag}^+(\text{aq}) + \text{e}^- \rightarrow \text{Ag}(\text{s})$ Anode: $2\text{H}_2\text{O}(\text{l}) \rightarrow \text{O}_2(\text{g}) + 4\text{H}^+(\text{aq}) + 4\text{e}^-$

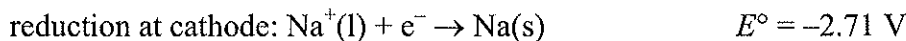
- 8 Silver anode would dissolve as the silver metal is oxidised.



which has a higher positive value of E° and therefore occurs in preference to



- 9 In electrolysis, the most positive E° values of possible half reactions at the electrodes will nominate which reaction occurs, e.g.



Reduction of water is preferred.

Other factors affecting products at anode and cathode:

- i nature of electrodes—refer to text page 378
- ii molten or aqueous electrolyte—refer to text page 377
- iii concentration of electrolyte—refer to text page 378

CHAPTER 22: CORROSION

Review exercise 22.1

- 1 Corrosion involves the oxidation of a metal to form positively charged ions by the loss of electrons. The electrons are generally transferred to atmospheric O_2 or other substances acting as oxidising agents.
- 2 A very thin coating of metal oxide on the surface of the metal can form a protective layer, preventing any further reaction between the metal and the oxidising agent.

Solutions Manual: Module 5

Shipwrecks, corrosion and conservation

Chemistry
Contexts 2
SECOND EDITION

- 3 Chromium, zinc, aluminium or manganese.

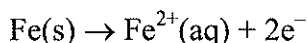
Review exercise 22.2

- 1 Ready availability. Economical extraction and refining methods.
- 2 Iron is an active metal susceptible to corrosion. Moist, salty sea conditions accelerate the rusting process. Rusting requires moisture and oxygen—conditions to which ships are always exposed.
- 3 An iron bar on the ground can trap moisture between the ground and the bottom layer. The underside becomes an anodic site where the iron oxidises. The surfaces of the iron bar exposed to atmospheric oxygen become cathodic sites of reduction. The moisture between the ground and the iron bar would contain certain dissolved salts which act as an electrolyte and would accelerate the rusting process.

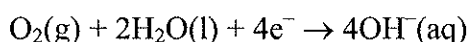
Iron nails stored in a sealed bottle would have atmospheric oxygen surrounding them but only water vapour in the air, so the rate of corrosion is much less.

- 4 a The differential aeration principle applies. Between the tightly woven central strands, water may be trapped and oxygen is excluded. These surfaces become anodic sites. The external strands are exposed to air and become cathodic sites.

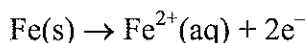
b Central strands, anodic sites:



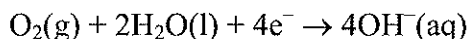
Outer strands, cathodic sites:



- 5 Copper is a less reactive metal than iron, and galvanic action occurs. The iron becomes anodic and corrodes:



The copper becomes cathodic where oxygen from the air is reduced:

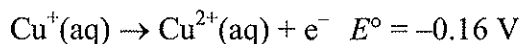
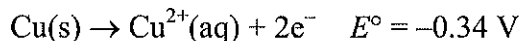


Review exercise 22.3

- 1 The magnesium is a sacrificial anode. It corrodes preferentially to the steel tank.
- 2 Pipelines may be painted, put at a negative potential at intervals, or have attached sacrificial anode blocks at intervals. They may also be mounted above ground to reduce corrosion by the differential aeration principle.
- 3 The standard reduction potential:



This is more likely to occur than the oxidation of copper atoms or the Cu^{+} ion:



The higher E° value of the reduction half equation for Cu^{2+} ions protects the metal from corrosion.

Chapter 22 Application and investigation

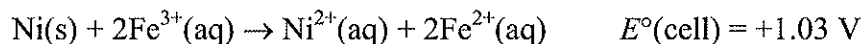
- 1 In coastal areas such as Kiama and Byron Bay, sea spray produces the necessary conditions for rusting—water, oxygen and electrolytic salts. These conditions promote accelerated rusting of steel structures compared to inland areas such as Dubbo where there is less water in the atmosphere and negligible electrolytic salts present in this atmospheric water.

- 2 Aluminium is a passivating metal which forms a very thin, but strongly adhering, layer of aluminium oxide on its surface. This oxide layer protects the metal from further oxidation and is not soluble in water.

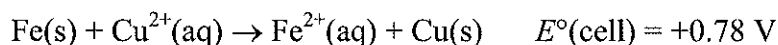
3 Investigation

- 4 a i Yes. No reaction between the nickel and iron(III) salt would occur.

ii No. The nickel can react with the iron(III) salt:



- b No. The steel tank would corrode:



- 5 Magnesium is a more active metal than iron. It would form its own protective oxide coating and protect the underlying steel. It would also act as a sacrificial anode if the magnesium layer were cracked. However, magnesium is readily attacked by mild acids.

Gold, copper and nickel are less reactive metals than iron. Copper and nickel will form their own protective oxide coating and gold will remain untarnished. All will protect the iron. However, any tiny gaps in the surface layer will lead to galvanic action in which the iron is preferentially oxidised. In addition, these are expensive metals.

- 6 Tin is a less reactive metal than iron. Once the tinplate of a can is broken, the iron will preferentially corrode by galvanic action.

Galvanised iron has a protective zinc coating. If the protective coating is broken, the zinc will preferentially corrode before iron because zinc is a more active metal than iron.

- 7 Aluminium forms a tenacious, impervious oxide layer on its surface.

Incorporating it with zinc in Zincalume[®] will enhance the protective oxide layer that zinc would form by itself.

Solutions Manual: Module 5

Shipwrecks, corrosion and conservation

Chemistry
Contexts 2
SECOND EDITION

- 8 Just below the surface the steel becomes the anodic site for oxidation. The sea water, rich in electrolytes, transfers the electrons to the steel surface exposed to atmospheric oxygen above the water, which then acts as the cathodic site.

Iron just under water dissolves away, while rust forming on the cathodic area flakes away faster due to the action of the sea.

- 9 a Magnesium bar: $\text{Mg(s)} \rightarrow \text{Mg}^{2+}(\text{aq}) + 2\text{e}^{-}$
Steel pipe: $2\text{H}_2\text{O(l)} + 2\text{e}^{-} \rightarrow \text{H}_2(\text{g}) + 2\text{OH}^{-}(\text{aq})$
b Electrons flow from the magnesium bar to the pipe.

- 10 Investigation

CHAPTER 23: CAN CHEMISTRY SAVE THE *TITANIC*?

Review exercise 23.1

- 1 Sunlight would not affect the temperature of water in deep, dark depths. There are fewer significant convection currents that would mix water from different depths.

2

Variable	Effect
Temperature	Increase temperature, increase reaction rate of corrosion.
Light	Increase light, increase photosynthetic aquatic organisms and their consumers, which could increase corrosion below water line.
Dissolved O ₂	Corrosion is greatest where [O ₂] is greatest. O ₂ is reduced at the cathode, as Fe is oxidised at anode site.
Dissolved CO ₂	As [CO ₂] increases, acidity increases as carbonic acid provides H ⁺ ions to promote reduction of O ₂ and so increase corrosion rate.
Salinity	As salinity increases, the number of ions increases. The electrolyte becomes more effective and so accelerates corrosion.

Review exercise 23.2

- 1 The lower temperatures would decrease the rate of the corrosion reaction.
- 2 Anaerobic bacteria are prevalent on ships since the hull provides a more ready supply of iron than sea water. The bacteria reduce sulfates to hydrogen sulfide, which in turn increases the acidity of the sea water. This promotes the reduction of O₂ as well as aiding in dissolving rust. Hydrogen sulfide also reacts with other metals to form insoluble metal sulfides.

Solutions Manual: Module 5

Shipwrecks, corrosion and conservation

Chemistry
Contexts 2
SECOND EDITION

- 3 Less active metals in sea water close to the steel hull accelerate the corrosion of iron. An electrochemical cell is set up with, for example, the less active copper acting as a cathode to the iron anode of the hull.

Review exercise 23.3

- 1 In oak artefacts, the cellular structure of the wood is destroyed by crystallising sulfate and chloride ions. Salt crystals in fine pores or cracks can distort the shape of an artefact, break it up or react chemically with it.
- 2 Oxidation of any exposed silver would take place, removing more silver from the coin.
- 3 Preservative of wood and it restores supple structure to leather.

Chapter 23 Application and investigation

1

Factor	a Surface sea water	b Deep sea water	Difference from a → b in rate of Fe rusting
Temperature	higher	low	Rate decreases with decrease in temperature.
Light intensity	high	low	Damaging sea life decreases with decrease in photosynthetic organisms together with associated consumers.
Dissolved O ₂	high	low	Oxidation of Fe decreases with reduction of oxygen levels.
Dissolved CO ₂	low	higher	As pH decreases with dissolving CO ₂ , the oxidation of Fe would be promoted.
Salinity	high	higher	Improved electrolytic action with more ions present would increase corrosion rate.

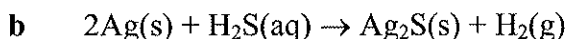
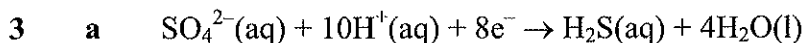
- 2
- a In deep waters it was expected that the lack of damaging sea life, salinity levels, freezing temperatures and low oxygen content would leave the *Titanic* well preserved.
 - b Galvanic action was set up between the steel and the presence on board of a number of other less active metals. Differential aeration caused by sediment or calcareous deposits from marine organisms resulted in high levels of localised corrosion. Oxygen levels were higher than anticipated. This increased the corrosion rate.

Solutions Manual: Module 5

Shipwrecks, corrosion and conservation

Chemistry
Contexts 2
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Slight lowering of pH levels due to the presence of anaerobic bacteria accelerated the reduction of O_2 and hence the oxidation of iron. Hydrogen ions may aid in the dissolving of rust.



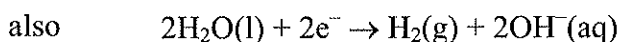
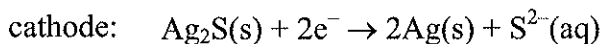
- 4 a In oak artefacts, the cellular structure of the wood is destroyed by crystallising sulfate and chloride ions. Salt crystals in fine pores or cracks can distort the shape of an artefact, break it up or react chemically with it.

b Treatment with weak acids such as methanoic acid or ammonium citrate. Mechanical cleaning.

c Chloride and sulfate ions are allowed to diffuse out of the wood by replacing the ionic solution with polyethylene glycol as a preservative.

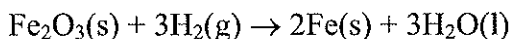
In leather, the salts are leached out by placing it in distilled water and then in a 30% PEG solution for approximately 2 weeks. The leather absorbs PEG to keep it supple even after drying.

- 5 a The formation of silver sulfide can be reversed by making the silver coin the cathode in an electrolyte cell:



The resulting $H_2(g)$ helps to loosen any corroded material on the surface of the coin.

- b Oxides and chlorides of iron may be reduced to form elementary iron if the affected object is placed in an alkaline solution and made into the cathode in an electrolysis reaction.



6–8 Investigation

Module 5

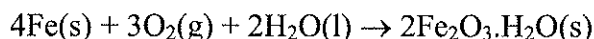
REVIEW

- 1 Galvanic action was set up between the steel and the presence on board of a number of other less active metals. Differential aeration caused by sediment or calcareous deposits from marine organisms resulted in high levels of localised corrosion. Oxygen levels were higher than anticipated. This increased the corrosion rate.

Slight lowering of pH levels due to the presence of anaerobic bacteria accelerated the reduction of O_2 and hence the oxidation of iron. Hydrogen ions may aid in the dissolving of rust.

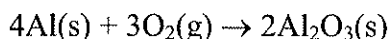
- 2
- a Paint prevents oxygen and water coming into contact with the iron.
 - b Cathodic protection of steel—use of a sacrificial anode such as Mg or Zn which oxidises preferentially to the iron, preventing the formation of Fe^{2+} ions. A sacrificial anode is attached to the hull at regular intervals and must be covered by sea water so that ions can migrate between anode and cathode.
 - c Iron alloyed with elements such as chromium, carbon, molybdenum and manganese form steels which are resistant to corrosion. Pure stainless steel effectively resists rust but is prohibitively expensive. Hulls of new ships now have surface stainless steel alloys which protect the bulk of the steel underneath from corrosion.
 - d Corrosion of steel requires the presence of O_2 , water and electrolytes in the water. The ocean environment has an abundance of sea water and sea spray containing many ions. O_2 is in the air and is dissolved in upper layers of the ocean. Unless steel is protected from the water and oxygen, the corrosion rate is very high.

- 3 Iron corrodes to form Fe^{3+} ions:

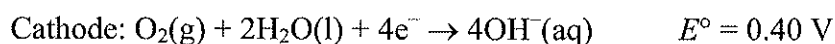
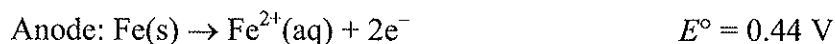


The resulting oxide is soft and porous, allowing O_2 and H_2O to pass through it to another Fe layer, which corrodes again.

Aluminium oxidises to form a very thin coat of aluminium oxide, which strongly adheres to the metal layer, is insoluble in water and thus forms a protective barrier against more oxidation occurring.



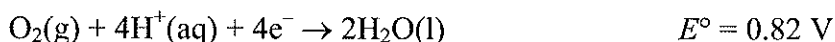
- 4 a For a reaction to occur spontaneously, the sum of the two half reactions in the redox reaction must have a positive E° value.



The sum of these two reactions is $E^\circ = +0.84 \text{ V}$

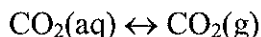
Hence, providing an electrolyte is present to allow migration of ions between electrodes, the reaction is spontaneous.

- b Acidic conditions could change the cathode reaction to:



which would increase the overall value of the redox reaction and hence accelerate the rusting process.

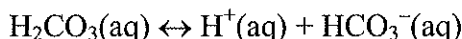
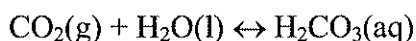
- 5 Soft drink is carbonated:



Releasing the pressure above the drink when the can is opened causes more $\text{CO}_2(\text{g})$ to come out of solution and the solution to go 'flat'. As temperature increases, the reaction rate would increase as well.

As temperature increases outside the refrigerator, the solubility of CO_2 in solution decreases and more CO_2 is released to the environment.

- 6 a Ca^{2+} ions are present in sea water. Decomposing organisms which act on paper and leather produce $\text{CO}_2(\text{g})$ which in turn reacts with water to form $\text{HCO}_3^-(\text{aq})$.



Thus the two ions $\text{Ca}^{2+}(\text{aq})$ and $\text{HCO}_3^-(\text{aq})$ can react to form calcium carbonate.

- b Careful mechanical cleaning and chemical cleaning with relatively weak acids such as methanoic acid or ammonium citrate.
- 7 a When twisted, the surface oxide layer will develop fine cracks and expose the metal. The orderly crystal structure of iron is distorted, making it easier for individual Fe atoms to break away from the crystal as Fe^{2+} ions from anodic oxidation.
- b Greater moisture in the air which contains sea salts acts as an effective electrolyte, which accelerates corrosion.
- c Zinc is a passivating metal which forms a coating to protect steel nails. If the coating is damaged, exposing the steel beneath, zinc will act as a sacrificial anode since it is oxidised more readily than iron.

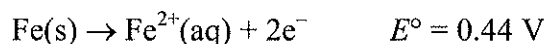
A tin coating also excludes oxygen and water from the steel nail surface, but if the steel is exposed, the iron has a lower ionisation energy than tin and will oxidise first.

- 8 Faraday established the basic laws of electrolysis that govern the quantitative relationships in electrolytic processes.

Faraday's 1st law—refer to text page 375

Faraday's 2nd law—refer to text page 375

- 9 a It is a sacrificial anode.
- b $\text{Zn}(\text{s}) \rightarrow \text{Zn}^{2+}(\text{aq}) + 2\text{e}^- \quad E^\circ = 0.76 \text{ V}$
 As the zinc is oxidised, it forms $\text{Zn}^{2+}(\text{aq})$, so must be replaced regularly.
- c The iron in ocean oil and gas rigs can corrode or oxidise according to the half-reaction

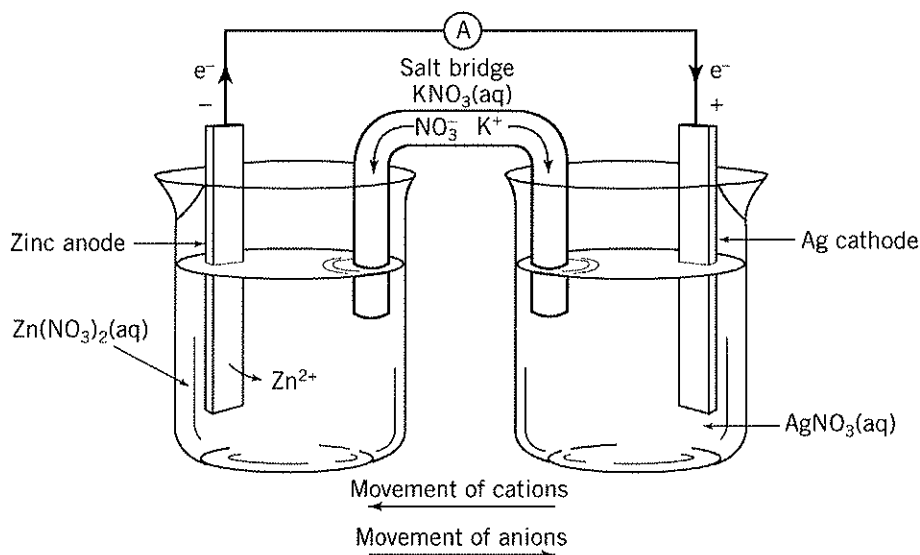


Any metal which has a more positive E° value than Fe(s) for the oxidation half-reaction will oxidise first and so can act as a sacrificial anode, provided it does not react with water itself.

Instead of Zn, you could use Cr, Mn, Al, Mg.

- 10 a** In a galvanic cell, a spontaneous chemical reaction takes place in which stored chemical energy is converted to electrical energy.

b



- c** anode: $\text{Zn(s)} \rightarrow \text{Zn}^{2+}(\text{aq}) + 2\text{e}^{-}$
 cathode: $\text{Ag}^{+}(\text{aq}) + \text{e}^{-} \rightarrow \text{Ag(s)}$

For every mole of Zn (65.39 g) lost at the anode, 2 mol of Ag (2×107.9 g) are deposited at the cathode.

Mass Zn lost : mass Ag deposited

65.39 g : 215.8 g

1 : 3.3

- 11 a** Copper is resistant to corrosion and has a higher ionisation energy value than Mg. This enables Mg to act as a sacrificial anode.

The oxidation half reaction for Cu(s) has $E^{\circ} = -0.34 \text{ V}$

Fe(s) has $E^{\circ} = +0.44 \text{ V}$

Mg(s) has $E^{\circ} = +2.37 \text{ V}$

The highest E° value will occur first.

- b From 11a, magnesium will have the greatest tendency to oxidise. As well as reducing O_2 , the electrons from magnesium can reduce any Fe^{2+} ions that are formed and so inhibit corrosion.
- c Underground pipes are exposed to O_2 and particularly water containing dissolved salts. The presence of an efficient electrolyte accelerates corrosion.
- 12 a Chemical weathering from terrestrial environments.
Hydrothermal vents in mid-ocean ridges.
- b Cl^- , SO_4^{2-}
- c *Desalination*: Leaching takes time. Chloride ions are difficult to remove and further electrolysis is required. Materials often have to be treated with preservatives.
- Electrolysis*: An example is the reduction of Ag_2S on silver objects with an inert anode in an alkaline solution. It is very effective as this method allows restoration of Ag markings on objects. Hydrogen gas produced by water reduction at the cathode on the surface of the object can help to loosen any flakes of corroded material.
- 13 Galvani joined two different metallic wires together and placed the unjoined ends into a freshly extracted frog muscle. The electric current that was generated contracted the muscle. Galvani thought the muscle had generated electricity, not the wires in the solution. Galvani is credited with the first generation of an electric current.
- Alessandro Volta showed that Galvani's frog muscle contraction was the consequence of 'metallic electricity' resulting from contact between the two different metals when he made the first battery with two different metals coming into moist contact with each other. He went on to develop the Voltaic Pile, the first direct current battery.
- Davy developed improved versions of Volta's pile, which he recognised as producing a source of electrons from a chemical reaction. Electric current could be used in electrolysis reactions to decompose water and prepare samples of the very reactive elements of potassium and sodium from their molten salts.
- Thus, Galvani unknowingly introduced the notion of electricity as being associated with differences between two different metals, Volta knowingly developed this idea and generated electricity in a prototype battery with the idea that something was able to flow between the metals, and Davy extended the concepts to chemical compounds.
- 14 a zinc, magnesium
- b $Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$ $E^\circ = +0.76\text{ V}$
 $Fe^{2+}(aq) + 2e^- \rightarrow Fe(s)$ $E^\circ = -0.44\text{ V}$

Solutions Manual: Module 5

Shipwrecks, corrosion and conservation

Chemistry
Contexts 2
SECOND EDITION

The E° value for the overall reaction is + 0.32 V, which indicates that the reaction can occur spontaneously. Electrons are lost at the zinc anode (oxidation) and transferred to the iron cathode.

- c Cathode. Reduction of any $\text{Fe}^{2+}(\text{aq})$ occurs through the electrons being lost by the sacrificial anode.
- 15 a $2\text{H}_2\text{O}(\text{l}) + 2\text{e}^- \rightarrow \text{H}_2(\text{g}) + 2\text{OH}^-(\text{aq}) \quad E^\circ = -0.83 \text{ V}$
- b 1 mole of electrons has a charge of 9.649×10^4 coulombs. For one mole of $\text{H}_2(\text{g})$ to be produced,
 $2 \times (9.649 \times 10^4) \text{ C}$ are needed.
For $7 \times 10^8 \text{ mol}$ of H_2 gas,
 $2 \times (9.649 \times 10^4) \times (7 \times 10^8) \text{ C}$ are needed = $1.351 \times 10^{14} \text{ C}$
- c $7.0 \times 10^8 \text{ mol}$ of H_2 gas is approximately $1.71 \times 10^{10} \text{ L}$ at 25°C and 101.3 kPa .
Vast quantities of H_2 bubbling to the surface would displace the air above the H_2 source, leading to a lack of O_2 for the crew.
 H_2 gas is highly flammable. With air it forms an explosive mixture.
- 16 a Reduced as silver ions gain electrons:
 $\text{Ag}^+(\text{aq}) + \text{e}^- \rightarrow \text{Ag}(\text{s})$
- b Aluminium metal acts as the anode in the galvanic cell that is set up, donating electrons to the silver ions.
Anodic oxidation: $\text{Al}(\text{s}) \rightarrow \text{Al}^{3+}(\text{aq}) + 3\text{e}^-$
- c An abrasive cleaner removes the silver content in the tarnish layer on the metal surface. Reduction of silver ions restores the silver to the object.
- 17 Crystallisation of Cl^- and SO_4^{2-} salts can cause considerable damage to the structure of materials such as wood and leather.
Non-metal porous artefacts must be leached of salts, and protected by preservatives and fungicides before they are brought to the surface and dried.
Artefacts must also be cleaned of calcium carbonate encrustations and sediments.
- 18 Shipwreck A: Much greater corrosion rate of hull if it is made of iron. Plentiful supply of O_2 . Does not dry out. Temperature high, good for reaction rate due to location. Hull in greater light, more organisms to aid in breakdown of materials. Because of shallow waters, artefacts of different metals have probably been removed.
- Shipwreck B: Limited supply of sea O_2 . Cold water. Lower number of destructive sea organisms. Anaerobic bacteria play larger role in corrosion. Interacting different metal artefacts could accelerate corrosion.

Solutions Manual: Module 5

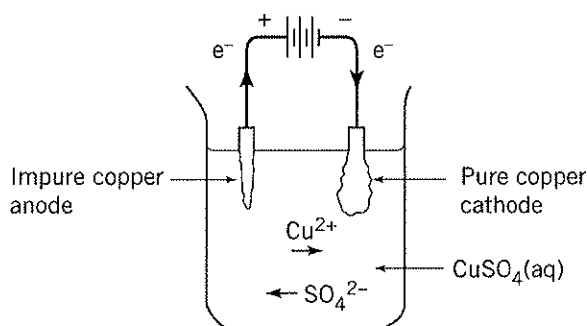
Shipwrecks, corrosion and conservation

Chemistry
Contexts 2
SECOND EDITION

- 19 a Low O_2 content of water; very low temperatures; lack of damaging sea life.
b Higher O_2 content in the deep water currents than expected, accelerated rate of corrosion of steel structure as oxygen reduced cathodically.
Presence of different metal artefacts set up galvanic corrosion in localised areas of shipwreck.

- 20 a In an electrolytic cell, electrical energy is converted to chemical energy. The reaction is not spontaneous and energy must be supplied.

b



- c $Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$
d Concentration of ions in electrolyte.
Quantity of electrical charge passing through the circuit.