Part 3: Contact with less reactive metals like copper increased the rate of corrosion. However, the nail in contact with zinc, which is more reactive than iron, showed little evidence of corrosion.
Part 4: The nail that experienced mechanical stress showed more blue deposits, indicating sites of iron oxidation. Blue deposits were also seen at the head, tip, and spiral edges of the nail: places where the nail was mechanically stressed while it was being manufactured.

Evaluation

(g) Student answers will vary. The investigation was fairly successful: we were able to see the effects of all four factors. The pink colour of some test tube solutions was too intense to allow us to see the corrosion of the nails clearly. We left our test tubes over four days, which may have been too long. It made detailed observations difficult. If we were doing this investigation again, we should make observations every day for four days.
(h) Controls are useful in this experiment to show how the nail would have changed under "normal" conditions before experimental variables are manipulated.
(i) Assuming that the solutions are made correctly (not contaminated) and that the nails used are not corrosion-resistant, there are few experimental errors or uncertainties in this experiment.
Boiling the water in Part 2 may not have effectively removed all the oxygen from the water. The only problem was the length of time we left the nails under their experimental conditions.

5.15 PREVENTING CORROSION

SECTION 5.15 QUESTIONS

(Pages 425–426)

Understanding Concepts

1. Painting prevents corrosion by isolating the metal from contact with its environment.
2. (a) Since aluminum is higher on the activity series, it should oxidize more readily than iron.
   (b) Although aluminum is more reactive than iron, aluminum protects itself from corrosion by forming a protective oxide layer that adheres well to the underlying metal. The oxide that iron forms, however, flakes off easily, exposing fresh iron that can be oxidized.
3. (a) A sacrificial anode is a piece of relatively reactive metal that is placed in electrical contact with the metal object to be protected from corrosion. The use of a sacrificial anode is a form of cathodic protection. The electrons released from the oxidation of the sacrificial anode prevent the object from oxidizing.
   (b) Iron would be the best choice to protect copper because it is the only metal of the three given that is more reactive (e.g., higher on the activity series) than copper.
4. (a) Impressed current and sacrificial anodes are both forms of cathodic protection. Both methods provide corrosion protection by sending electrons into the metallic object to be protected, preventing the object from losing electrons and being oxidized by its environment.
   (b) The use of a sacrificial anode is a method that involves the consumption of another chemical. As long as the anode metal remains in electrical contact with the metal to be protected, and until it is all corroded away, the protection continues. Impressed current, on the other hand, is an electrical method that does not involve any other chemical substance. This method provides protection only while an external supply of electrical energy is maintained.
5. Physical properties: strong, stiff, have a good degree of springiness, and should resist being bent.
   Chemical properties: completely unreactive with any of the substances that could commonly enter the mouth.

Applying Inquiry Skills

6. (a) The nail stored in salt water without a coating of grease is badly corroded. The coated nail shows little evidence of corrosion.
   (b) This is an example of applying a protective coating to prevent corrosion.
   (c) This method provides corrosion protection by completely isolating the metal from its environment, which prevents the metal from reacting with oxygen and water.
   (d) The main disadvantage of a protective coating is that the metal remains protected only while the coating remains intact. A small crack or other imperfection in the coating could quickly become the site of corrosion.
7. (a) The nail with the zinc attached shows little evidence of corrosion, although the zinc has developed a pale-grey coating. The control nail (with no zinc) is visibly rusting.
   (b) This is an example of cathodic protection.

(c) Cathodic protection prevents corrosion by supplying the iron with electrons. In this case, zinc oxidizes more readily than iron. Electrons released by the oxidation of zinc flow to iron, preventing iron from losing its electrons and oxidizing.

(d) The use of a sacrificial anode is effective as long as the anode is present. The anode metal must be replaced periodically to maintain corrosion protection.

Making Connections

8. (a) An underbody oil spray protects the car by isolating the car body from the environment. Oil has an uncanny ability to creep into tiny cracks or folds in metal and provide protection. Furthermore, because water is a polar substance and oil is nonpolar, any water that comes into contact with the oil surface cannot penetrate the oil, but quickly slides off.

(b) Some of the disadvantages of oil sprays are that they tend to be messy, dirt can accumulate in the oil, and they need to be reapplied each season.

(c) Some "no drip" undercoats are mixtures of oil, wax, and rust-inhibiting chemicals. The mixture is first heated until it has the viscosity of water and is then applied to the car. As the mixture cools, the wax hardens against the surfaces it is applied to, trapping the oil with it, preventing the oil from dripping.

9. (a) A Galvalume coating consists of approximately 55% aluminum and 45% zinc, by mass.

(b) Galvalume steel products are used for applications requiring a high degree of corrosion resistance. These applications include: industrial and commercial roofing and siding, steel framing materials used in construction, automotive underbody parts, playground equipment, guide rails, home laundry appliances, and air-conditioning equipment.

10. (a) Materials engineering technologists regularly perform the following tests:
testing the hardness and tensile strength of the product
measuring the ease with which the steel can be shaped into objects such as car bumpers
testing the thickness of coatings on a steel product
analyzing the chemical composition of scrap steel before it is used to manufacture new steel
testing and maintaining the chemicals, such as sulfuric acid, that are used in the plant
checking for microscopic defects in steel samples using a scanning electron microscope

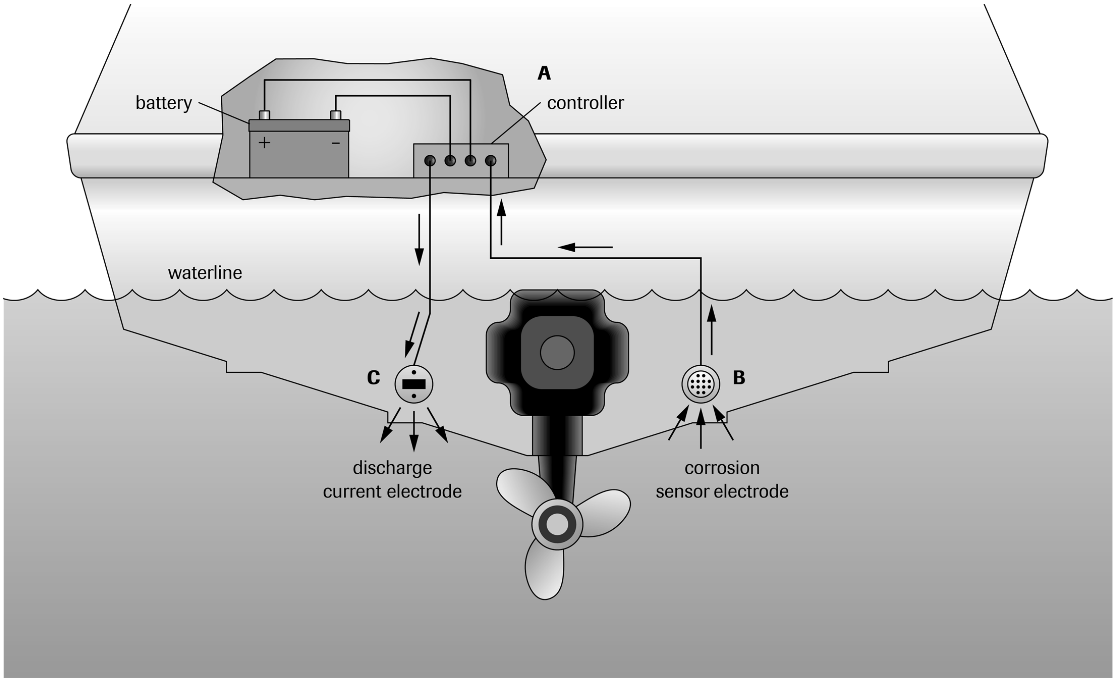
(b) Most of the tests are physical tests: they test physical properties of materials. Few of the tests involve chemical reactions.

(c)
- Personal skills:
  decision-making skills
  strong problem-solving skills
  an specific aptitude for technological problem-solving
  good oral and written communication skills
  strong computer skills
  the ability to learn new technical skills quickly
  the ability to work well independently as well as in a team
- Educational background and length of study:
  The engineering technologist will have completed secondary school with English and math at least at the College Prep level. He or she would also have completed a two- or three-year college program specifically designed for this field. Some companies offer apprenticeship programs for students coming directly out of high school.
- College programs:
  Mohawk College in Hamilton, Ontario, offers a specific program for metallurgical engineering technologists. Northern College, with campuses in Timmins, Kirkland Lake, and Haileybury, has a welding engineering technology program.
- Salary and working conditions:
  Entry-level salaries in this field can range from $30 000 to $45 000, while average salaries can range from $45 000 to $ 60 000. Materials engineering technologists often work as members of a quality control team, monitoring the quality of the product in an industrial operation such as steel making.

Extension

11. The "Mercathode Protection System" is designed to protect a metal boat from a specific form of corrosion known as galvanic corrosion. This type of corrosion results when two different metals are in contact with each other in the presence of an electrolyte. The Mercathode Protection System protects boats in the same way as an impressed current protects an underground steel pipeline. A small electric current from the boat's battery is sent to a possible corrosion site on the boat.

As the metal of the boat begins to corrode, a small current flow is generated. Sensors in the Mercathode Protection System detect this current and send a message to a controlling unit of the system that pumps electrons from the boat's battery to the corrosion site. The inflow of electrons prevents further corrosion from occurring. The amount of current drawn from the battery is usually quite small and should not drain the battery.



5.16 ACTIVITY: IMPRESSED CURRENT

(Pages 427–428)

Observations

Control nail in test tube: The solution slowly turned pink.
U-tube: cathode: The solution around the nail became pink.
anode: Bubbles of gas were observed at the graphite surface. No colour changes were observed.

Analysis

(a) Only the nail in the test tube showed any evidence of corrosion. The colour of the solution changed to blue (the colour of hexacyanoferrate(III) indicator with $Fe^{2+}_{(aq)}$ ions) around the nail. This indicates that the oxidation of iron was occurring.
(b) The nail in the cell could not corrode because electrons were being pumped into it, preventing the nail from being oxidized. The other nail had no such protection, so was free to corrode.
(c) The pink colour observed on the nail side of the U-tube is the characteristic colour of phenolphthalein in a base. Therefore, hydroxide ions were being produced and the second half-reaction probably occurred.

Synthesis

(d) The reactions would occur very slowly or not at all. The presence of salt improves the electrical conductivity of the solution.
(e) Oxidation of iron would take place at the anode because electrons are being pulled out of the anode by the battery. Consequently, the solution should turn blue in colour as $Fe^{2+}_{(aq)}$ ions combine with the hexacyanoferrate(III) indicator.
(f) Without power protection, the nail would begin to corrode in the salt water. As a result, the solution should change colour to blue as $Fe^{2+}_{(aq)}$ ions combine with the hexacyanoferrate(III) indicator.
(g) If a steady, uninterrupted supply of current cannot be maintained, impressed current is not an effective method of corrosion protection.