(e) The measured cell potentials were all lower than the predicted values.

Evaluation

(f) Sources of experimental error or uncertainty include small measurement uncertainties in the solution preparation and the voltmeter readings, cleanliness of the metal strips, purity of the metals and solutions, and the non-standard conditions of temperature. Without knowing the value of all of these uncertainties, but guessing that they will be relatively small, we can see that the overall quality of the evidence is about medium.
(g) In each case, the prediction of the cathode and anode was correct.
(h) The agreement between the predicted and measured potentials appears to be acceptable but they are either less than, equal to, or only slightly greater than 5%.
(i) All measured cell potentials are less than the predicted values. This suggests some systematic error for all cells. Perhaps this is because the temperature was less than the standard 25°C and/or the metals or solutions were not completely pure. The voltmeter could also be reading consistently low.
(j) The design is adequate to answer the problem with no obvious flaws. However, the procedure used does have some inadequacies. The temperature was controlled, but was not set at the standard value. This should be improved to eliminate some uncertainties in the results. The purity of the metals and accuracy of the solution concentration are not known, but otherwise, the materials appear adequate.

INVESTIGATION 9.6.1 THE CORROSION OF IRON

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Prediction

(a) According to my experience and a table of relative strengths of oxidizing and reducing agents, the presence of oxygen, water, electrolytes, acidic solutions, and other metals may affect the rate of corrosion of iron. It is general knowledge that air and water are required and that iron rusts faster if ordinary salt is present. Furthermore, if any oxidizing agents that appear above iron in the table of relative strengths of oxidizing and reducing agents are present, then a spontaneous corrosion or reaction should take place; e.g., oxygen and water, and oxygen in an acidic solution.

Materials

(b) lab apron
eye protection
bottle of distilled water
8 small test tubes with stoppers
2 50-mL beakers
test-tube rack
masking tape
tweezers
10 pieces of iron wire or nails (5–6 cm)
fine sandpaper or steel wool
1 piece of magnesium ribbon (5–6 cm)
1 piece of copper wire (5–6 cm)
2 small carbon rods
2 9-V batteries
4 connecting wires
deaerated water (freshly boiled)
about 50 mL of alcohol (or acetone) in a 250-mL beaker
0.10 mol/L $HCl_{(aq)}$, $NaCl_{(aq)}$, and $NaOH_{(aq)}$

Procedure

(c)
1. Clean each piece of iron thoroughly with fine sandpaper or steel wool until the iron is silvery in appearance.
2. Drop all of the cleaned iron pieces into a beaker with alcohol and swirl for a few seconds. Remove the iron pieces using tweezers and place the pieces on a clean paper towel. As much as possible, avoid directly handling the iron.
3. Label 8 small, clean test tubes.
4. For test tube 1, make sure it is dry, add a piece of iron, and stopper.
5. Fill test tube 2 with boiled distilled water (deaerated water) and then add a piece of iron and stopper.
6. For test tubes 3–6, add about 2–3 cm depth of the specified liquid and a piece of iron, and then stopper: 3, with distilled water; 4, $HCl_{(aq)}$; 5, $NaCl_{(aq)}$; 6, $NaOH_{(aq)}$.

7. For test tube 7, firmly wrap a piece of cleaned magnesium ribbon around the iron. Add this to 2–3 cm of distilled water in the test tube and then stopper.
8. For test tube 8, firmly wrap a piece of cleaned copper wire around the iron. Add this to 2–3 cm of distilled water in the test tube and then stopper.
9. Tape a 9-V battery to the side of each of two small beakers so that the bottom of the beaker and the battery coincide. Approximately half-fill each beaker with distilled water.
10. Use two connecting wires to connect an iron piece to the negative terminal of one battery and a carbon rod to the positive terminal. Be sure that the two electrodes do not touch. Label this setup as 9.
11. Use two connecting wires to connect an iron piece to the positive terminal and a carbon rod to the negative terminal of the other battery. Be sure that the two electrodes do not touch. Label this setup as 10.
12. Record any observations for each of the 10 containers.
13. Record further observations in two days.
14. When all observations are completed, dispose of all liquids into the sink and return the iron and other materials.

Evidence

(d)

#	Substances/Conditions	Observations – Day 1	Observations – Day 3
1	Fe in dry, empty test tube	no change	no change
2	Fe in deaerated water (full)	no change	very slight yellow-brown tinge in water; little change in iron
3	Fe in distilled water	some slight yellow-brown colour near wire	some yellow-brown solid on wire and at bottom of test tube
4	Fe in $HCl_{(aq)}$	gas bubbles rising from iron	iron appears mostly clean in liquid but some dark deposits on the part of iron above liquid; stopper popped off
5	Fe in NaCl	some slight yellow-brown colour in water	extensive yellow-brown and dark brown deposit at bottom of test tube and some on iron
6	Fe in NaOH	no change	no change
7	Mg-wrapped Fe in distilled water	tiny gas bubbles	no change to iron; dark deposit on magnesium and grey-black deposit at bottom of test tube
8	Cu-wrapped Fe in distilled water	dark colour on iron; yellow-brown colour near wire	yellow-brown precipitate on iron and at bottom; copper wire still very shiny
9	Fe connected to negative terminal of a battery	no change	no change to iron; few dark bits of material at bottom of beaker
10	Fe connected to positive terminal	slightly darker iron	considerable yellow-brown and dark solid on iron and throughout beaker; dark froth at carbon electrode

Analysis

(e) According to the evidence, the corrosion of iron is accelerated by the presence of both water and air, salt in the water, contact with copper metal, and connection to the positive terminal of a battery.

(f) Little or no corrosion appears if: no water is present, no air is present, the solution is basic, iron is in contact with magnesium, and iron is connected to the negative terminal of a battery. The result for hydrochloric acid is uncertain. It appears that both air and water need to be present for significant corrosion to occur. When these are present, a basic solution, contact with magnesium, or a connection to a negative terminal all appear to counteract the effect of air and water.

Evaluation

(g) The design of this experiment is adequate to answer the general question asked in the problem with no major flaws. The design could be improved by clearly specifying the variables and controls in this experiment and adding more specific tests such as a test for iron ions in the solutions and precipitates. This would make the results more certain.

(h) Both the procedure and materials appear to be adequate to obtain the kind of information required by the problem. An improvement in the procedure would be to find a more efficient method of cleaning the iron before the experiment. A better way of assessing the extent of corrosion would also be useful. Perhaps the iron wire could be examined under a microscope to look for evidence of corrosion. Also, evidence for the presence of iron ions could be obtained.

(i) The main sources of experimental error or uncertainty include the purity and cleanliness of the iron wire, how well water or air was eliminated in # 1 and # 2, and the qualitative judgment of any corrosion.

(j) Overall, the evidence seems to be reasonably good for an initial laboratory study of corrosion and I am fairly confident of the results obtained.

(k) Most of the prediction appears to be qualitatively verified. However, the results obtained were much more specific than predicted, with a few unexpected results; e.g., with acidic and basic solutions. No prediction was made for the effect of an external power supply. Experimenting with a battery provided a starting point but is unacceptable for detailed predictions.

(l) Personal experience and the table of relative strengths of oxidizing and reducing agents appear somewhat useful but other factors also play an unexpected role. To make better predictions of all factors, especially electrical factors, requires more empirical and theoretical knowledge about electrochemistry and corrosion.

CHAPTER 9 SUMMARY

MAKE A SUMMARY

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