

- No evidence of reaction was visible after several minutes. After several days, long silvery crystals formed on the silver electrode in cells (b) and (c), the copper solution appeared darker, and some blue-coloured solution had moved toward the silver side of the cell. The voltage of the cell slowly decreased until, after several weeks, the voltage of the cell was almost zero volts.

- (g) A suitable control would be an identical cell with no electrical connection (wire) between the electrodes.
- (h) Silver half-cell: Test the concentration of silver ions several times by removing a known volume of the solution and precipitating the silver ions as silver chloride. Measure the mass of the silver electrode at the beginning and at the end. Copper half-cell: Using colour standards (or a spectrophotometer), determine the concentration of copper ions several times using a sample of the solution. (Alternatively, the concentration of copper ions could be determined by precipitation.) Measure the mass of the copper electrode at the beginning and at the end.
Salt bridge: Note the colour changes in the solution.
- (i) Nitrates are spectator ions and should be the same for all cells as a control.

INVESTIGATION 9.5.1 INVESTIGATING GALVANIC CELLS

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Prediction

- (a) According to redox concepts and the table of redox half-reactions ...

Cathode (+)				Anode (–)			Cell potential (V)
Cu _(s)		Cu ²⁺ _(aq)		Pb ²⁺ _(aq)		Pb _(s)	+0.47
Ag _(s)		Ag ⁺ _(aq)		Cu ²⁺ _(aq)		Cu _(s)	+0.46
Cu _(s)		Cu ²⁺ _(aq)		Zn ²⁺ _(aq)		Zn _(s)	+1.10
Ag _(s)		Ag ⁺ _(aq)		Pb ²⁺ _(aq)		Pb _(s)	+0.93
Pb _(s)		Pb ²⁺ _(aq)		Zn ²⁺ _(aq)		Zn _(s)	+0.63
Ag _(s)		Ag ⁺ _(aq)		Zn ²⁺ _(aq)		Zn _(s)	+1.56

Experimental Design

- (b) Individual metal–metal ion half-cells are constructed. Different combinations are connected with a salt bridge and the electrodes, and the cell potentials are determined. The independent variable is the combination of half-cells and the dependent variable is the cell potential. Controlled variables are temperature and electrolyte concentration.

Procedure

- (c) 1. Clean metal strips with steel wool and rinse with distilled water.
2. Assemble two of the four metal–metal ion half-cells, for example, copper and lead.
3. Connect the copper half-cell with the lead half-cell using the salt bridge.
4. Use the voltmeter and connecting wires to determine the cathode and anode of the cell.
5. With the voltmeter connected to the cell, measure the initial voltmeter reading.
6. Remove and rinse the salt bridge.
7. Repeat steps 1 to 5 for the remaining combinations of half-cells.
8. Clean and return the metal strips and recycle the electrolyte solutions.

Evidence/Analysis

- (d)

Cathode (+)				Anode (–)			Predicted potential (V)	Measured potential (V)	Percent diff. (%)
Cu _(s)		Cu ²⁺ _(aq)		Pb ²⁺ _(aq)		Pb _(s)	+0.47	+0.46	2
Ag _(s)		Ag ⁺ _(aq)		Cu ²⁺ _(aq)		Cu _(s)	+0.46	+0.45	2
Cu _(s)		Cu ²⁺ _(aq)		Zn ²⁺ _(aq)		Zn _(s)	+1.10	+1.06	4
Ag _(s)		Ag ⁺ _(aq)		Pb ²⁺ _(aq)		Pb _(s)	+0.93	+0.88	5
Pb _(s)		Pb ²⁺ _(aq)		Zn ²⁺ _(aq)		Zn _(s)	+0.63	+0.59	6
Ag _(s)		Ag ⁺ _(aq)		Zn ²⁺ _(aq)		Zn _(s)	+1.56	+1.47	6

- (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 $\text{HCl}_{(\text{aq})}$, $\text{NaCl}_{(\text{aq})}$, and $\text{NaOH}_{(\text{aq})}$

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, $\text{HCl}_{(\text{aq})}$; 5, $\text{NaCl}_{(\text{aq})}$; 6, $\text{NaOH}_{(\text{aq})}$.