(c) % difference $= \dfrac{\mid \text{experimental value} - \text{predicted value} \mid}{\text{predicted value}} \times 100\%$

$= \dfrac{\mid 1.8\ \text{A} - 1.85\ \text{A} \mid}{1.85\ \text{A}} \times 100\%$

% difference $= 2\%$

The ammeter accuracy appears reasonably good. However, this is a tentative conclusion because the precision of the experiment is poor.

Making Connections

19. (a) The plastic is made conductive by a chemical dipping of the cleaned/treated plastic to make an adhering layer of copper or nickel/palladium.
    (b) The surface must be thoroughly cleaned and etched by removing some surface plastic molecules. In one process for ABS plastic, the initial layer is catalytic palladium, which is then covered with a layer of nickel. In other processes, copper is deposited first. In all cases, several other layers of metal are then added, usually by electrolysis, to produce the final plated product.
    (c) An important limitation is the ability to create molecular-size pits in the plastic surface to adhere the initial metal layer. Metal plating plastics makes them less flexible and the plating may crack. As a general rule, if the object has to bend, then it should not be plated. Selective plating may be used with some objects.
20. Chromium from electroplating waste solutions can be removed by first reducing the chromium from the +6 oxidation state to the +3 state using a reducing agent such as sodium bisulfite. The chromium(III) ions are then precipitated as a nontoxic chromium(III) hydroxide.

# UNIT 5   PERFORMANCE TASK: ELECTROPLATING

(Page 762)

Purpose

The purpose is to create a process for plating copper onto a metal object.

Question

What design produces a smooth layer of copper metal that adheres to a metal object?

Prediction

(a) According to the redox concepts in this unit and some Internet research, a metal object can be plated at the cathode of a copper(II) sulfate electrolytic cell. The key independent variable is the electric current. The best plating should occur at relatively low currents because this produces a relatively low rate of plating. The assumption is that the quality of the copper plating will be better if it forms more slowly.

$$Cu^{2+}_{(aq)} \quad + 2\ e^- \quad \rightarrow \quad Cu_{(s)}$$

$$n_{e-} = \dfrac{It}{F} \qquad\qquad n_{Cu} = n_{e-} \times \dfrac{1}{2}$$
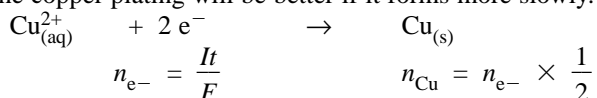
The amount of copper formed depends directly on the amount of electrons transferred. The amount of electrons per unit of time depends directly on the current.
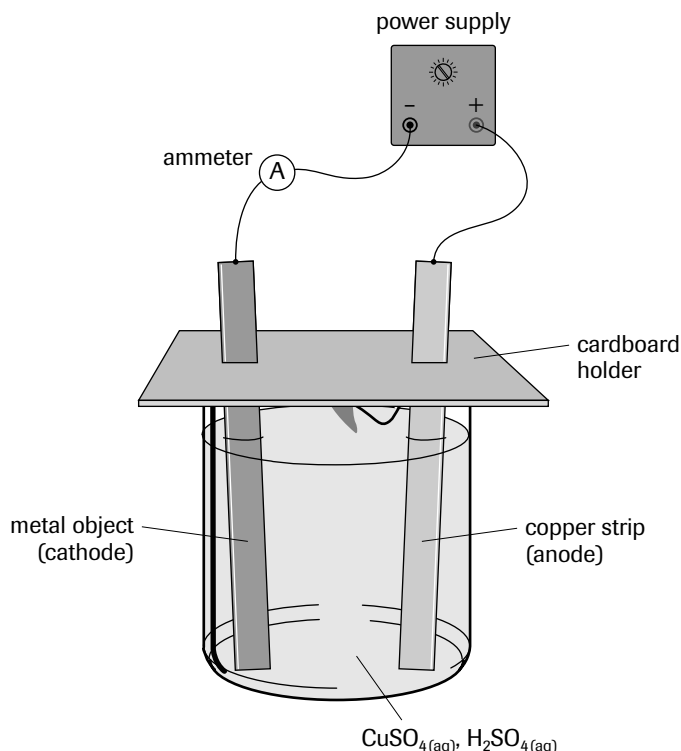
Experimental Design

A small metal object is carefully cleaned and plated with copper. The dependent variable is the quality of the copper plating as determined by its thickness, appearance, and adherence to the object.

(b) The following electrolytic cell is constructed.

metal object $\mid CuSO_{4(aq)},\ H_2SO_{4(aq)} \mid Cu_{(s)}$
cathode $(-)$ anode $(+)$
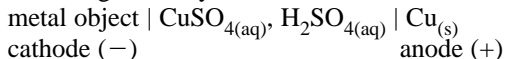
Based on other copper-plating cells, copper(II) sulfate is acidified with a sulfuric cell.

(c) The independent variable used is the electric current. Other potential variables that are held constant are: surface area of the metal in the solution; cleaning of the metal surface; distance between the electrodes; charge transferred ($q = It$); and the composition, concentration, and temperature of the electrolyte.

power supply

ammeter (A)

cardboard holder

metal object (cathode)

copper strip (anode)

$CuSO_{4(aq)}$, $H_2SO_{4(aq)}$

Materials

(d) lab apron
   eye protection
   150-mL beaker
   three 250-mL beakers
   cardboard holder
   pure copper strip
   4 stainless steel objects (e.g., lab scoopulas)
   connecting wires
   digital multimeter
   variable power supply
   steel wool
   stirring rod
   paper towel
   bottle of distilled water
   clock
   acetone
   0.50 mol/L $CuSO_{4(aq)}$
   0.50 mol/L $H_2SO_{4(aq)}$ (corrosive, rinse with water on contact)

CAUTION:

Copper sulfate solution is toxic and an irritant. Sulfuric acid is corrosive. If either of them comes into contact with skin or clothing, rinse with lots of water.

Procedure

1. Set up three 250-mL beakers with about 200 mL each of distilled water, sulfuric acid, and acetone.
2. Carefully clean the stainless steel objects and the copper strip with steel wool. Rinse with distilled water.
3. Place the 4 steel objects and the copper for about 1 min into the 250-mL beaker of sulfuric acid, then the distilled water, and finally, the acetone.
4. Remove the metal strips and lay them out on a paper towel to dry. Be careful to handle the metals only by the end that will not be in the electrolyte.

5. Using the markings on the beaker, add 70 mL of $CuSO_{4(aq)}$ and 70 mL of $H_2SO_{4(aq)}$ to the 150-mL beaker and stir.
6. Insert the copper strip into a slit in the cardboard holder and one of the steel objects into the other slit. Arrange the metals so that they will reach the bottom of the beaker.
7. Connect the electrodes to the meter and power supply, making sure that the copper is the anode (+, red) and the steel object is the cathode (–, black).
8. Check all connections before plugging the power supply into the electrical outlet.
9. Turn on the power supply and note the time on the clock. Quickly adjust the power supply for a current of 0.050 A.
10. During the operation of the cell, make any small adjustments necessary to keep the current constant.
11. Shut off the power supply after 30.0 min and unplug.
12. Carefully remove the steel object, and dip it into the beaker of distilled water and then into the beaker of acetone. Set it on a paper towel to dry.
13. Dispose of the acidic electrolyte into the container labelled "Recycled acidic copper(II) sulfate."
14. Repeat steps 5 to 13, using 0.150 A for 6.0 min, 0.500 A for 3.0 min, and 0.750 A for 2.0 min.
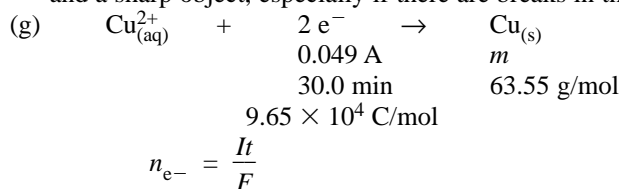15. Clean and return all of the metals for reuse.

Evidence

Electroplating of Stainless Steel Objects				
Object	Initial appearance	Current (A)	Time (min)	Observations of final plating
1	shiny, silver	0.049	30.0	• somewhat shiny, light reddish-brown patches • does not rub off on paper or finger • comes off fairly easily with steel wool • very little plating on the back of the object
2	shiny, silver	0.249	6.0	• somewhat shiny, light reddish-brown in a smooth even layer • does not rub off with paper or finger • when rubbed lightly with steel wool, became more shiny and did not rub off • plating can be removed by scraping with a sharp object • some plating on the back of the object
3	shiny, silver	0.503	3.0	• darker, reddish-brown, fairly dull layer • rubs off easily with paper and finger • back of object is plated like the front of #2
4	shiny, silver	0.750	2.0	• darkest, red-brown layer with some light and dull, dark patches • appears thicker and quite granular • rubs off very easily with paper or finger • back of object is plated like the front of #2

- Each stainless steel object was about 1.5 cm wide, 15 cm long, and about 6 cm immersed in electrolyte.

- The distance between the electrodes was about 4 cm.

Analysis

(f) In general, the lower currents produce a thin layer of copper that is shiny and adheres reasonably well to the metal object. The larger currents produce a darker, duller, loose deposit that immediately wipes off to expose the original metal finish. The best copper plating appears to be at a current of about 0.250 A, although about 0.050 A may be as good if left longer to cover the whole surface of the object. Even the best plating can be removed with a little effort and a sharp object, especially if there are breaks in the surface.

(g)

$$Cu^{2+}_{(aq)} \quad + \quad 2\,e^- \quad \rightarrow \quad Cu_{(s)}$$

0.049 A $\quad m$

30.0 min $\quad$ 63.55 g/mol

9.65×10^4 C/mol

$$n_{e-} = \frac{It}{F}$$

$$= \frac{0.049 \; \cancel{C/s} \; \times \; 30.0 \; \cancel{min} \; \times \; 60 \; \cancel{s/min}}{9.65 \times 10^4 \; \cancel{C}/mol}$$

$$n_{e^-} = 9.1 \times 10^{-4} \; mol$$

$$n_{Cu} = 9.1 \times 10^{-4} \; \cancel{mol \; e^-} \times \frac{1 \; mol \; Cu}{2 \; \cancel{mol \; e^-}}$$

$$n_{Cu} = 4.6 \times 10^{-4} \; mol$$

$$m_{Cu} = 4.6 \times 10^{-4} \; \cancel{mol} \times \frac{63.55 \; g}{1 \; \cancel{mol}}$$

$$m_{Cu} = 2.9 \times 10^{-4} \; g$$

The other masses of copper deposited were very similar because the charge was controlled. For objects 2, 3, and 4, the mass of copper deposited was 3.0×10^{-2} g.

Evaluation

(h) In general, the design appears adequate to answer the question because it appears that electric current is a significant variable that affects the plating process. The materials were adequate, although the power supply was a little difficult to control to a predetermined value of the current. However, this would not seem to be a major problem. I am uncertain about the purpose and effect of acidifying the copper(II) sulfate with sulfuric acid. The procedure seemed to work well and gave sufficient evidence to answer the question.

(i) The design seems to be promising because the final results were relatively clear. However, even the best plating could be scratched off with a little effort. Either a better surface preparation or a protective layer (e.g., a varnish) may be needed to produce a better plated object. The object was plated mostly on the side facing the anode, which is not very good if you want all sides of the object to be plated. Some of the other controlled variables need to be investigated to see if some other combination of variables, along with a low current, can improve the plating.

(j) Some minor adjustments include a better control of the power supply, and perhaps mixing the electrolyte during the process. Some major adjustments include rotating the object to plate it on all sides and creating a surface to which the copper might adhere better (perhaps a rougher or pitted surface).

(k) Two things were learned. One is that plating is not as easy as it sounds in a textbook. Secondly, there are many possible variables that make the discovery of the right combination of them a very long trial-and-error process of experimentation.

UNIT 5   SELF-QUIZ

(Page 764)

1. True
2. False: Reduction is the gain of electrons and occurs at the *cathode* ~~anode~~ of any cell.
3. False: Oxidation is the ~~decrease~~ *increase* in oxidation number and reduction is the *decrease* ~~increase~~ in oxidation number.
4. True
5. False: Inert electrodes are required for *some* ~~all~~ electrolytic cells.
6. True
7. True
8. False: The cell potential is determined by *subtracting* ~~adding~~ the reduction potentials for the two half-cell reactions.
9. True
10. False: A standard hydrogen–cobalt cell has a cell potential of ~~−0.28~~ *+0.28* V.
11. False: In a standard copper–lead cell, lead is the *anode* ~~cathode~~ and copper is the *cathode* ~~anode~~.
12. True
13. False: The charge transferred by a 1.5-A current in a time of 2.0 min is *1.8 × 10²* ~~3.0~~ C.
14. True
15. True
16. True
17. False: ~~Both tin and zinc plating work equally well in inhibiting the corrosion of iron.~~ *Zinc inhibits iron corrosion much better than tin, because its reduction potential is lower than that of iron.*
18. False: Large *electrolytic* ~~galvanic~~ cells are used to refine metals and to produce nonmetals like chlorine.