Applying Inquiry Skills

12. SOA $Tl^{+}_{(aq)} + e^{-} \rightleftharpoons Tl_{(s)}$

$In^{3+}_{(aq)} + 3\,e^{-} \rightleftharpoons In_{(s)}$

$Ga^{3+}_{(aq)} + 3\,e^{-} \rightleftharpoons Ga_{(s)}$

$Al^{3+}_{(aq)} + 3\,e^{-} \rightleftharpoons Al_{(s)}$ SRA

Making Connections

13. Ursula Franklin specializes in the structure of metals and alloys and has pioneered the study of metallurgy in ancient cultures. In her view, science and technology have a side-by-side realtionship, stimulating and utilizing each other. She has voiced serious concerns about Canada's lack of support for research in science and technology. She is a tireless worker for Science for Peace, and has worked to improve opportunities for women in science and to make scientific information understandable and accessible to the public.

9.4 TECHNOLOGY OF CELLS AND BATTERIES

PRACTICE

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Understanding Concepts

1. A simple electric cell contains two solid conductors (electrodes) and an aqueous conductor (electrolyte).
2. An electrode is a solid conductor and an electrolyte is an aqueous conductor. An anode is the negative electrode in an electric cell. A cathode is the positive electrode in an electric cell.
3. Four cells are needed. ($6\ V \times 1.5\ V/cell = 4$ cells)
4. Electric current is a measure of the rate of flow of charge past a point in an electric circuit. Voltage is a measure of the energy difference per unit charge.

Making Connections

5. From a scientific perspective, a diagram shows where the electrons are believed to enter and exit the device. From a technological perspective, a diagram shows how the batteries should be placed in the device to make it work and to avoid damaging certain components.

PRACTICE

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Understanding Concepts

6. Scientific knowledge may be used to describe, explain, or predict the parts or operation of a device. Technological problem solving is used to develop a device that works based on established criteria.
7. The steps involved in technological problem solving are:
   - Develop a general design, for example, select variables to manipulate and control.
   - Follow several prediction–procedure–evidence–analysis cycles, manipulating and systematically studying one variable at a time.
   - Complete an evaluation on criteria such as efficiency, reliability, cost, and simplicity.
8. A technical and safety problem is the possible leakage of the liquid electrolyte. The electrolyte should be changed to a moist paste to reduce this problem.
9. Primary cells, such as the alkaline dry cell or mercury cell, cannot in practice be recharged. Secondary cells, such as the Ni–Cad cell, NiMH cell, or lead–acid cell, can be recharged repeatedly.
10. Advantages of the zinc chloride dry cell include simplicity, reliability, and relatively low cost. The main disadvantage is that the cell is not rechargeable and must be discarded when depleted. Other possible disadvantages for certain uses include short shelf life, relatively low current produced, and constancy of voltage.

Making Connections

11. The AA, C, and D cells differ in size, current produced, and longevity of the cell, but the cell potential remains the same in each cell size. The smaller the cell, the smaller the electrodes and the smaller the current produced.
12. Both designs use containers that are consumed as they are used.

13. (a) Some of the requirements for cells used in electronic devices are:
    - long life
    - small size
    - constant voltage during its active life
    - reliable for many recharges
    - inexpensive

    (b) The storage capacity of some rechargeable batteries is reduced if they are recharged before being totally drained, because they then may only discharge to the point where they were recharged previously. Such batteries are sometimes referred to as having a "memory."
14. The original Molicel featured a "jelly roll" design in which sheets of a lithium metal foil (anode), molybdenum disulfide coated on aluminum foil (cathode), and a microporous separator were coiled up and inserted into a steel can. A non-aqueous, liquid electrolyte solution (containing lithium ions) was added to the can and the can was sealed. The original design has been modified to produce a safer cell. Some of the advantages of Molicels (and other lithium ion batteries) compared to other types of secondary cells are: higher current, lighter weight, more energy, and ability to work over a wider temperature range.

PRACTICE

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Understanding Concepts

15.

Perspective	Advantage	Disadvantage
technological	• high efficiency • high-energy density • lightweight	• requires constant supply of fuel • some cells require pressurized gases
economic		• high cost
environmental	• very little pollution	

16. Some potential uses of fuel cells are in electric cars, electric buses, and for large-scale commercial and industrial electricity generation.
17. **Hydrogen–oxygen fuel cell**:

$$O_{2(g)} + 2\,H_2O_{(l)} + 4\,e^- \rightarrow 4\,OH^-_{(aq)} \quad \text{(reduction)}$$

$$2\,H_{2(g)} + 4\,OH^-_{(aq)} \rightarrow 4\,H_2O_{(l)} + 4\,e^- \quad \text{(oxidation)}$$

$$O_{2(g)} + 2\,H_{2(g)} \rightarrow 2\,H_2O_{(l)}$$

(Half-reactions in Table 2 refer to an alkaline hydrogen–oxygen fuel cell as used by NASA.)

Aluminum–air fuel cell:

$$3\,O_{2(g)} + 6\,H_2O_{(l)} + 12\,e^- \rightarrow 12\,OH^-_{(aq)} \quad \text{(reduction)}$$

$$4\,Al_{(s)} \rightarrow 4\,Al^{3+}_{(aq)} + 12\,e^- \quad \text{(oxidation)}$$

$$3\,O_{2(g)} + 6\,H_2O_{(l)} + 4\,Al_{(s)} \rightarrow 4\,Al^{3+}_{(aq)} + 12\,OH^-_{(aq)}$$

$$3\,O_{2(g)} + 6\,H_2O_{(l)} + 4\,Al_{(s)} \rightarrow 4\,Al(OH)_{3(s)}$$

18. Some problems that must be solved before the Ballard cell sees widespread use are:
    - finding an inexpensive and abundant source of hydrogen gas
    - developing a safe way to store hydrogen in a vehicle
    - if the first two problems can't be solved, finding a substitute for hydrogen fuel
    - reducing the cost of the cells
19. Some advantages of methanol over hydrogen or natural gas are:
    - easy transportation and storage
    - industrial manufacture of methanol is well established
    - relatively inexpensive
    - renewable resource

Making Connections

20. (a) anode: $Pb_{(s)}$; cathode: $PbO_{2(s)}$; electrolyte: $H_2SO_{4(aq)}$
    (b) The large currents are produced by designing electrodes with a large surface area.
    (c) The main social impact of this battery is to enable widespread use of motor vehicles for personal transportation.
    (d) The lead and acid in used car batteries can have a negative impact on the environment.
21. Plastic batteries are unique in having electrodes made of conducting "doped" polymers rather than metallic materials. In some recent plastic cells, the electrolyte as well is made of a polymer material — resulting in a "leakproof" battery that contains no liquid. Charging involves ion migration to the electrodes, but the electrodes themselves do not charge, making such cells theoretically rechargeable through a very large number of cycles. The cells are very lightweight, may be almost any shape, and have high-energy density and power density characteristics, making them of great interest to designers of satellites. A significant advantage is that such cells operate through a very wide range of temperatures without much change in their electrical properties. Another strong social advantage is that they contain no environmentally harmful materials. Currently, such cells are very expensive and do not store very large quantities of energy, but development continues.

Explore an Issue: Debate: Hydrogen Fuel Cells

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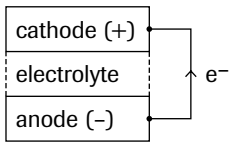
(a) (Sample points to consider ...)

- Most current proposals will use hydrogen stripped from methanol or gasoline, although natural gas is another potential hydrogen source.
- If some fossil fuel is used as a source of hydrogen, carbon dioxide is still produced in the cell and there may be substantial environmental effects of producing the hydrogen-rich fuels, such as methanol and gasoline.
- The cost of fuel-cell cars will be quite high until mass production lowers the unit cost. The economic effects on communities that depend on the well-established oil and gas industry, and internal-combustion vehicle production for employment may be significant. Political issues such as taxation, environmental regulations, and lobbies from special interest groups need to be considered.
- Some alternatives include hybrid vehicles; generating hydrogen from renewable, nonpolluting sources such as sunlight and wind; and storing hydrogen in carbon nanotubes or graphite fibres.

SECTION 9.4 QUESTIONS

(Page 694)

Understanding Concepts

1. 

2. The chemical changes that occur at the electrodes provide the evidence that an electric cell involves a redox reaction. Reduction always occurs at the cathode (e.g., aqueous metal ions changing to solid metal), and oxidation always occurs at the anode (e.g., solid metal changing to aqueous metal ions).
3. The three types of electric cells used in consumer and commercial operations are primary cells, secondary cells, and fuel cells. Primary cells cannot in practice be recharged. Secondary cells can be recharged repeatedly. Fuel cells produce electricity by the reaction of a fuel that is continuously supplied to keep the cell operating.
4. Two common examples of consumer cells are alkaline dry cells, which are used in flashlights and radios, and Ni–Cad cells, which are used in power tools, shavers, and portable computers.
5. (a) The electrons flow from the zinc to the silver in the external circuit.
   (b) Zinc is the anode and silver is the cathode.
   (c) $Ag_2O_{(s)} + H_2O_{(l)} + Zn_{(s)} \rightarrow 2\,Ag_{(s)} + Zn(OH)_{2(s)}$

Making Connections

6. If cells and batteries did not exist, we would have to live without many commonplace conveniences, such as portable radios, flashlights, and flash cameras. Portable electronic devices, such as cordless phones, cellular phones, laptop computers, disc players, and digital cameras, would not exist. Starting a vehicle would have to be done the old-fashioned way—with a hand crank!

7. (a) Internal-combustion engines are a major source of pollution and environmental damage. Electric cars powered by hydrogen fuel cells are seen as "pollution free."
   (b) The number of lead–acid batteries needed to power an electric car would make the car very heavy. Used lead–acid batteries are a major source of lead pollution.
   (c) Advances in hydrogen fuel cells could make electric cars the "green" solution to pollution from internal-combustion engines.
8. Consumer magazines are a good source of information on cells and batteries, regarding their reliability, cost, simplicity of use, safety (leakage), size (volume), shelf life, active life, energy density, power capacity, maintenance, disposal, environmental impact, and ability to be recharged.
9. Lithium–iodine batteries are commonly used in pacemakers, but some are powered by radioactive isotopes. Conventional pacemaker batteries last from four to eight years, depending how much the heart uses the pacemaker. A doctor tracks signals from the pacemaker to ascertain when the battery is nearing the end of its life. Rechargeable batteries generally hold less energy, and would need to be replaced more often.

9.5 GALVANIC CELLS

PRACTICE

(Page 700)

Understanding Concepts

1. A galvanic cell is an arrangement of two half-cells that spontaneously produces electricity.
   A half-cell is an electrode–electrolyte combination forming one-half of a complete cell.
   A porous boundary is a barrier that separates electrolytes while still permitting the movement of ions.
   An inert electrode is a solid conductor that serves as an anode or a cathode in a voltaic cell, but is chemically unreactive.
2. A cathode is the electrode where reduction occurs.
   An anode is the electrode where oxidation occurs.
3. (a) cathode
   (b) anode
   (c) anode
   (d) cathode
4. An inert electrode is used in a half-cell where no conducting solid is involved in the half-reaction equation.
5. The solution in a salt bridge must be a "spectator" electrolyte chemically; that is, its ions must not react with the half-cell ions that pass through.
6. (a) SOA

$$Ag_{(s)} \mid Ag^{+}_{(aq)} \parallel Zn^{2+}_{(aq)} \mid Zn_{(s)}$$

SRA

cathode $\quad 2\,[Ag^{+}_{(aq)} + e^{-} \rightarrow Ag_{(s)}]$

anode $\quad Zn_{(s)} \rightarrow Zn^{2+}_{(aq)} + 2\,e^{-}$

net $\quad 2\,Ag^{+}_{(aq)} + Zn_{(s)} \rightarrow Ag_{(s)} + Zn^{2+}_{(aq)}$