Iron electrodes have been used as anodes in rechargeable battery systems since the introduction of the nickel-iron rechargeable battery at the turn of the century by Junger in Europe and Edison in the United States. Even today the batteries are produced in a fashion similar to the original construction. New constructions have been developed which give better high-rate performance and have lower manufacturing costs. Today the nickel-iron battery is the most common rechargeable system using iron electrodes. Iron-silver batteries have been tested in special electronic applications, and iron/air batteries have shown promise as motive power systems. The characteristics of the iron battery systems are summarized in Tables 25.1 and 25.2.

As designed by Edison, the nickel-iron battery was and is almost indestructible. It has a very rugged physical structure and can withstand electrical abuse such as overcharge, over-discharge, discharged stand for extended periods, and short-circuiting. The battery is best applied where high cycle life at repeated deep discharges is required (such as traction applications) and as a standby power source with a 10- to 20-year life. Its limitations are low power density, poor low-temperature performance, poor charge retention, and gas evolution on stand. The cost of the nickel-iron battery lies between the lower-cost lead-acid and the higher-cost nickel-cadmium battery in most applications, with the exception of limited use applications in electric vehicles and mobile industrial equipment.

Most recently, iron electrodes have been considered and tested as cathodes too. Based upon high valence state iron, Fe(VI), these cathodes have shown promise in experimental cells when coupled with zinc or metal hydride anodes for portable primary and secondary batteries. The results are discussed in Sec. 25.7.

*Ralph J. Brodd was the original author for this chapter.
### Table 25.1 Iron Electrode Battery Systems

<table>
<thead>
<tr>
<th>System</th>
<th>Uses</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron/nickel oxide (tubular)</td>
<td>Material handling vehicles, underground mining vehicles, miners’ lamps, railway cars and signal systems, emergency lighting</td>
<td>Physically almost indestructible</td>
<td>High self-discharge Hydrogen evolution on charge and discharge</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Not damaged by discharged stand</td>
<td>Low power density</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Withstands electrical abuse: overcharge, overdischarged, short-circuiting</td>
<td>Lower energy density than competitive systems</td>
</tr>
<tr>
<td>Iron/air</td>
<td>Motive power</td>
<td>Good energy density</td>
<td>Low efficiency Hydrogen evolution on charge</td>
</tr>
<tr>
<td>Iron/silver oxide</td>
<td>Electronics</td>
<td>High energy density</td>
<td>Low self-discharge Hydrogen evolution on charge</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High cycle life</td>
<td>High cost Hydrogen evolution on charge</td>
</tr>
</tbody>
</table>

### Table 25.2 System Characteristics

<table>
<thead>
<tr>
<th>System</th>
<th>Nominal voltage, V</th>
<th>Specific energy Wh/kg</th>
<th>Energy density Wh/L</th>
<th>Specific power W/kg</th>
<th>Cycle life, 100% DOD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron/nickel oxide</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tubular</td>
<td>1.4</td>
<td>30</td>
<td>60</td>
<td>25</td>
<td>4000</td>
</tr>
<tr>
<td>Developmental</td>
<td>1.4</td>
<td>55</td>
<td>110</td>
<td>110</td>
<td>&gt;1200</td>
</tr>
<tr>
<td>Iron air</td>
<td>1.2</td>
<td>80</td>
<td>110</td>
<td>60</td>
<td>1000</td>
</tr>
<tr>
<td>Iron/silver oxide</td>
<td>1.48</td>
<td>105</td>
<td>160</td>
<td>—</td>
<td>&gt;300</td>
</tr>
</tbody>
</table>

### 25.2 Chemistry of Nickel-Iron Batteries

The active materials of the nickel-iron battery are metallic iron for the negative electrode, nickel oxide for the positive, and a potassium hydroxide solution with lithium hydroxide for the electrolyte. The nickel-iron battery is unique in many respects. The overall electrode reactions result in the transfer of oxygen from one electrode to the other. The exact details of the reaction can be very complex and include many species of transitory existence.\(^2\rightarrow^4\) The electrolyte apparently plays no part in the overall reaction, as noted in the following reactions:

\[
Fe + 2\text{NiOOH} + 2\text{H}_2\text{O} \xrightarrow{\text{discharge}} 2\text{Ni(OH)}_2 + \text{Fe(OH)}_2 \quad \text{(first plateau)}
\]

\[
3\text{Fe(OH)}_2 + 2\text{NiOOH} \xrightarrow{\text{charge}} 2\text{Ni(OH)}_2 + \text{Fe}_3\text{O}_4 + 2\text{H}_2\text{O} \quad \text{(second plateau)}
\]
The overall reaction is

$$3\text{Fe} + 8\text{NiOOH} + 4\text{H}_2\text{O} \xrightarrow{\text{discharge}} \xleftarrow{\text{charge}} 8\text{Ni(OH)}_2 + \text{Fe}_3\text{O}_4$$

The electrolyte remains essentially invariant during charge and discharge. It is not possible to use the specific gravity of the electrolyte to determine the state of charge as for the lead-acid battery. However, the individual electrode reactions do involve an intimate reaction with the electrolyte.

A typical charge-discharge curve of an iron electrode is shown in Fig. 25.1. The two plateaus on charge correspond to the formation of the stable +2 and +3 valent states of the iron reaction products. The reaction of the iron electrode can be written as

$$\text{Fe} + n\text{OH}^- \rightarrow \text{Fe(OH)}^{2-}_n + 2e \quad \text{(first plateau)}$$

and

$$\text{Fe(OH)}^{2-}_n \rightarrow \text{Fe(OH)}_2 + n\text{OH}^-$$

$$\text{Fe(OH)}_2 + \text{OH}^- \rightarrow \text{Fe(OH)}_3 + e \quad \text{(second plateau)}$$

Then

$$2\text{Fe(OH)}_3 + \text{Fe(OH)}_2 \rightarrow \text{Fe}_3\text{O}_4 + 4\text{H}_2\text{O}$$

Iron dissolved initially as the +2 species in alkaline media. The divalent iron complexes with the electrolyte to form the Fe(OH)$_{2-n}$ complex of low solubility. The tendency to supersaturate plays an important role in the operation of the electrode and accounts for many important aspects of the electrode performance characteristics. Continued charge forms the +3 valent iron which, in turn, interacts with +2 valent iron to form Fe$_3$O$_4$.
The superior life-cycling characteristics of the iron electrode result from the low solubility of the reaction intermediates and oxidized species. The supersaturation on discharge results in the oxidized material forming small crystallites near the reaction site. On charge, the low solubility also slows the crystal growth of the iron, thereby helping to ensure formation of the original active high-surface-area structure. The low solubility also accounts for poor high-rate and low-temperature performance as the discharged (oxidized) species precipitate at or near the reaction site and block the active surface. The performance characteristics are substantially improved, however, in the advanced nickel-iron batteries by the use of a superior electrode grid structure, such as fiber-metal, which provides intimate contact with the iron active material throughout the volume of porous structure.

Sulfide addition to the iron electrode radically changes the electrocrystallization kinetics. It increases the supersaturation and makes reaction more reversible. Sulfide also absorbs on the surface to block crystallization sites and raises the hydrogen evolution reaction on charge. Lithium salt additions seem to make the electrode perform more reversibly, perhaps by enhancing the solubility of the reaction intermediates.

Nickel electrode reactions are generally thought to be solid-state-type reactions wherein a proton is injected or rejected from the lattice reversibly on discharge and on charge, respectively.

\[
\begin{align*}
\beta\text{-Ni(OH)}_2 & \xrightarrow{\text{transformation}} \alpha\text{-Ni(OH)}_2 \\
\text{reduction} & \quad \| \quad \text{oxidation} & \quad \| \quad \text{reduction} \\
\text{(discharge)} & \quad \| \quad \text{(charge)} & \quad \| \quad \text{(charge)} \\
\beta\text{-NiOOH} & \xrightarrow{\text{overcharge}} \gamma\text{-NiOOH}
\end{align*}
\]

The oxidation (charge) voltage for the \(\alpha\) and \(\beta\) materials is more positive than the discharge voltage by 60 mV and 100 mV, respectively. The \(\beta\text{-Ni(OH)}_2\) is the usual electrode material. It is converted on charge to \(\beta\text{-NiOOH}\) with about the same molar volume. On overcharge the \(\gamma\) structure can form. This form also incorporates water and potassium (and lithium) into the structure. Its molar volume is about 1.5 times the \(\beta\) form. This is thought to be responsible in large part for the volume expansion (swelling) which occurs on charging the battery. The \(\alpha\) form then results on discharge of the \(\gamma\) form. Its molar volume is about 1.8 times the \(\beta\) form, and the electrode can swell further on discharge. On discharge stand in concentrated electrolyte, the \(\alpha\) form converts to the \(\beta\) form. Cobalt additions (2 to 5%) improve the charge acceptance (reversibility) of the nickel electrode.

### 25.3 CONVENTIONAL NICKEL-IRON BATTERIES

#### 25.3.1 Construction

The construction of a tubular or pocket plate nickel-iron cell is shown in Fig. 25.2. The active materials are filled in nickel-plate perforated steel tubes or pockets. The tubes are fastened into plates of desired dimensions and assembled into cells by interleaving the positive and negative plates. The container is fabricated from nickel-plated sheet steel. The cells may be assembled into batteries in molded nylon cases or mounted into wooden traps. The steel cases may be coated with plastic or rubber for insulation or spaced by insulating buttons.

The manufacturing process has remained relatively unchanged for over 50 years. The processes are designed to produce materials of highest purity and with special particle characteristics for good electrochemical performance.
Negative Electrode. To produce the anode active material, pure iron is dissolved in sulfuric acid. The FeSO₄ is recrystallized, dried, and roasted (815 to 915°C) to Fe₂O₃. The material is washed free of sulfate, dried, and partially reduced in hydrogen. The resulting material (Fe₂O₃ and Fe) is partially oxidized, dried, ground, and blended. Small amounts of additives, such as sulfur, FeS, and HgO, are blended in to increase battery life by acting as depassivators, reducing gas evolution, or improving conductivity.

To make the anode current collector, steel strips or ribbon are perforated and nickel-plated. After drying and annealing, the strip is formed into a pocket, about 13 mm wide and 7.6 mm long. One end is left open and filled with the iron active material. A machine automatically introduces the active material and tamps it into the pockets. After filling, the negative pockets are crimped and pressed into openings in a nickel-plated steel frame.

Positive Electrode. The positive active material consists of nickel hydroxide in alternate layers with nickel flake. High-purity nickel powder or shot is dissolved in sulfuric acid. The hydrogen evolved is used in making the iron active material. The acidity of the resulting solution is adjusted to pH 3 to 4 and filtered to remove ferric iron and other insoluble materials. If needed, the solution may be further purified to remove traces of ferrous iron.
and copper. Cobalt sulfate may be added in the proportion of 1.5% to improve nickel electrode performance. The nickel sulfate solution is sprayed into hot 25 to 50 NaOH solution. The resulting slurry is filtered, washed, dried, crushed, and screened to yield particles which pass 20- but not 200-mesh screens.

Special nickel flake (1.6 \times 0.01 \text{ mm}) is produced by electrodeposition of alternate layers of nickel and copper on stainless steel. The electroplate is stripped and cut into squares. The copper is dissolved out in hot sulfuric acid, and the resulting nickel flakes are washed free of copper and dried at low temperature to prevent nickel oxide formation. With a modified process the flakes of proper shape and size can be produced as a single layer, eliminating the need for deposition of alternate copper layers. As in the negative electrode, the positive-electrode process starts with perforated steel ribbon which is nickel-plated and annealed. The ribbon is wound into tubes with an interlocked seam. Two types, right- and left-wound tubes, are produced, typically of 6.3-mm diameter. The tubes are filled with alternate layers of nickel hydroxide and nickel flakes. Each layer is tamped (144 kg/cm²) to ensure good contact. There are 32 layers of flake per centimeter. To prevent the seam from opening during the rigors of charge and discharge, rings are placed around the tubes at uniform intervals of about 1 cm. The tubes are enclosed, and the pinched ends are locked into the nickel-plated steel grid frame. The “rights” and “lefts” are alternated so that any tendency to distort on the part of one tube is counteracted by the next one. The positive electrode can also be made in the pocket plate construction, as described above under “Negative Electrode.”

**Cell Assembly.** The configuration and size of the tubes and pockets determine the capacity for each plate. The plates are then assembled into electrodes to meet the capacity requirements of each cell.

Each plate group is assembled by bolting a terminal pole and a selected number of plates, depending on capacity, to a steel rod which passes through the grid at the top of the plates. Groups of positive and negative plates are intermeshed to form the element. A cell usually contains one or more negative than positive plates. The cells are made positive limiting for best cycle life.

The positive and negative plates are separated by hard rubber or plastic pins called “hair pins” or “hook pins,” which fit into spaces formed by the tubular positive and flat negative electrodes.

**Electrolyte.** The electrolyte is a 25 to 30% KOH solution with up to 50 g/L of LiOH added. The composition of the replacement electrolyte to compensate for losses due to spray from the vent cap is about 23% caustic with about 25 g/L LiOH. Occasionally the electrolyte is replaced completely to rejuvenate the cell performance. The renewal electrolyte is about 30% KOH with 15 g/L LiOH.

Lithium additions to the electrolyte are important but not completely understood. Lithium hydroxide improves cell capacity and prevents capacity loss on cycling and also seems to facilitate nickel electrode kinetics. It expands the working plateau on charge and delays oxygen evolution. Some evidence exists for the formation of Ni\(^{4+}\), which improves electrode capacity. Lithium also decreases the carbonate content in the electrolyte since Li\(_2\)CO\(_3\) is not very soluble. It also decreases the tendency for swelling of the positive active material but increases the resistivity of the cell electrolyte.

Shortly after initiation of charge, hydrogen evolution begins on the iron electrode. The considerable hydrogen evolution on charge presumably helps counteract iron passivation in alkaline solution. Mercury additions also have a similar effect, but only in the early formation cycles.
25.3.2 Performance Characteristics of Nickel-Iron Battery

**Voltage.** A typical discharge-charge curve of a commercial iron/nickel oxide battery is shown in Fig. 25.3. The battery’s open-circuit voltage is 1.4 V; its nominal voltage is 1.2 V. On charge, at rates most commonly used, the maximum voltage is 1.7 to 1.8 V.

**Capacity.** The capacity of the nickel-iron battery is limited by the capacity of the positive electrode and, hence, is determined by the length and number of positive tubes in each plate. The diameter of the tubes generally is held constant by each manufacturer. The 5-h discharge rate is commonly used as the reference for rating its capacity.

The conventional nickel-iron battery has moderate power and energy density and is designed primarily for moderate to low discharge rates. It is not recommended for high-rate applications such as engine starting. The high internal resistance of the battery lowers the terminal voltage significantly when high rates are required. The relationship between capacity and rate of discharge is shown in Fig. 25.4.

![FIGURE 25.3 Typical voltage characteristics during constant-rate discharge and recharge. (From Ref. 9.)](image1)

![FIGURE 25.4 Curves of capacity vs. discharge rate at 25°C; end voltage 1.0 V per cell. (From Ref. 9.)](image2)
If a battery is discharged at a high rate and then at a lower rate, the sum of the capacities delivered at the high and low rates nearly equals the capacity that would have been obtained at the single discharge rate. This is illustrated in Fig. 25.5.

**Discharge Characteristics.** The nickel-iron battery may be discharged at any current rate it will deliver, but the discharge should not be continued beyond the point where the battery nears exhaustion. It is best adapted to low or moderate rates of discharge (1- to 8-h rate). Figure 25.6 shows the discharge curves at different rates of discharge at 25°C.

![Figure 25.5](image1.png) **FIGURE 25.5** Effect of decreasing rate on battery voltage of nickel-iron cell.

![Figure 25.6](image2.png) **FIGURE 25.6** Time-voltage discharge curves of nickel-iron battery; end voltage 1.0 V per cell. *(From Ref. 9.)*
**Effect of Temperature.** Figure 25.7 shows the effects of temperature on the discharge. The capacity at 25°C is normally taken as the standard reference value. The decrease in performance is generally attributed to passivity of the iron electrode and decreased solubility of the reaction intermediate. At low temperature, increased resistivity and viscosity of the electrolyte along with slower nickel electrode kinetics contribute to the fall-off of capacity. Care must be exercised to keep the temperature from exceeding about 50°C as the self-discharge of the nickel positive electrode is accelerated. Also, the increased solubility of iron at high temperature can adversely affect operation of the nickel electrode by incorporating soluble iron into the nickel hydroxide crystal lattice. The battery is seldom used below −15°C.

**Hours of Service.** The hours of service on discharge that a typical nickel-iron battery, normalized to unit weight (kilograms) and volume (liters), will deliver at various discharge rates and temperatures is summarized in Fig. 25.8.

![Figure 25.7](image1.png)  
**FIGURE 25.7** Effect of temperature on capacity at various rates. (From Ref. 9.)

![Figure 25.8](image2.png)  
**FIGURE 25.8** Hours of service of nickel-iron battery at various discharge rates and temperatures; end voltage 1.0 V cell.
Self-Discharge. The self-discharge rate, charge retention, or stand characteristic of the nickel-iron battery is poor. At 25°C a cell will lose 15% of its capacity in the first 10 days and 20 to 40% in a month. At lower temperatures the self-discharge rate is lower. For example, at 0°C the losses are less than one-half of those experienced at 25°C.

Internal Resistance. To a rough approximation, the internal resistance $R_i$ can be estimated for tubular Ni-Fe from the equation

$$R_i \times C = 0.4$$

where $R_i$ = internal resistance, $\Omega$

$C$ = battery capacity, Ah

For example, $R_i = 0.004 \, \Omega$ for a 100-Ah battery. The value of $R_i$ remains constant through the first half of the discharge, then increases about 50% during the latter half of the discharge.

Life. The main advantages of the tubular-type nickel-iron battery are its extremely long life and rugged construction. Battery life varies with the type of service but ranges from 8 years for heavy duty to 25 years or more for standby or float service. With moderate care, 2000 cycles can be expected; with good care, for example, by limiting temperatures to below 35°C, cycle life of 3000 to 4000 cycles has been achieved.

The battery is less damaged by repeated deep discharge than any other battery system. In practice, an operator will drive a battery-operated vehicle until it stalls, at which point the battery voltage is a fraction of a volt per cell (some cells may be in reverse). This has a minimal effect on the nickel-iron battery in comparison with other systems.

Charging. Charging of the batteries can be accomplished by a variety of schemes. As long as the charging current does not produce either excessive gassing (spray out of the vent cap) or temperature rise (above 45°C), any current can be used. Excessive gassing will require more frequent addition of water. If the cell voltage is limited to 1.7 V, these conditions should not be a consideration. Typical charging curves are given in Fig. 25.9. The Ampere-hour input should return 25 to 40% excess of the previous discharge to ensure complete charging. The suggested charge rate is normally between 15 and 20 A per 100 Ah of battery capacity. This rate would return the capacity in the 6- to 8-h time frame. The effect of temperature on charging is shown in Fig. 25.10.

![FIGURE 25.9](https://example.com/fig259.png) Typical charging voltage for nickel-iron battery at various rates. (From Ref. 9.)
Constant current and modified constant potential (taper), shown in Fig. 25.11, are common recharging techniques. The charging circuit should contain a current-limiting device to avoid thermal runaway on charge. Recharging each night after use (cycle charging) is the normal procedure. The batteries can be trickle-charged to maintain them at full capacity for emergency use. A trickle charge rate of 0.004 to 0.006 A/Ah of battery capacity overcomes the internal self-discharge and maintains the battery at full charge. Following an emergency discharge, a separate recharge is needed. For applications such as railroad signals, charging at a continuous average current may be the most economic method. Here a modest drain is required when no trains are passing but quite a heavy drain when a train passes, yet the total Ampere-hours over a period of 24 h remains fairly constant. For this situation, a constant current equal to that required to maintain the battery can be used.

**FIGURE 25.10** Variation of relay operating voltage with temperature. (From Ref. 9.)

**FIGURE 25.11** Effects of "regulators" with voltage and current regulation. (From Ref. 9.)

### 25.3.3 Sizes of Nickel-Iron Batteries

Nickel-iron batteries have been available in sizes ranging from about 5 to 1250 Ah. In recent years they have become less popular, giving way to the lead-acid and nickel-cadmium batteries, and are no longer manufactured by many of the original manufacturers. Table 25.3 lists the physical and electrical characteristics of typical nickel-iron batteries.
### TABLE 25.3 Typical Nickel-Iron Batteries

<table>
<thead>
<tr>
<th>Nominal capacity, Ah</th>
<th>169</th>
<th>225</th>
<th>280</th>
<th>337</th>
<th>395</th>
<th>450</th>
<th>560</th>
<th>675</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal current, A:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5-h discharge</td>
<td>34</td>
<td>45</td>
<td>56</td>
<td>67</td>
<td>79</td>
<td>90</td>
<td>112</td>
<td>135</td>
</tr>
<tr>
<td>Cell weight, filled, kg</td>
<td>8.8</td>
<td>10.8</td>
<td>12.9</td>
<td>15.3</td>
<td>17.4</td>
<td>19.5</td>
<td>24.3</td>
<td>28.6</td>
</tr>
<tr>
<td>Installed weight, kg</td>
<td>9.8</td>
<td>12.0</td>
<td>14.3</td>
<td>16.9</td>
<td>19.3</td>
<td>21.7</td>
<td>26.5</td>
<td>31.2</td>
</tr>
<tr>
<td>Electrolyte (1.17 kg/L), kg</td>
<td>1.8</td>
<td>2.2</td>
<td>2.6</td>
<td>3.0</td>
<td>3.4</td>
<td>3.8</td>
<td>4.9</td>
<td>5.9</td>
</tr>
<tr>
<td>Cell dimensions, mm*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length</td>
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<td>66</td>
<td>82</td>
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<td>Battery dimensions, mm†:</td>
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<td>Length:</td>
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<tr>
<td>2 cells</td>
<td>—</td>
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<td>—</td>
<td>—</td>
<td>265</td>
<td>295</td>
<td>321</td>
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</tr>
<tr>
<td>3 cells</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>376</td>
<td>421</td>
<td>460</td>
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<tr>
<td>4 cells</td>
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<td>367</td>
<td>431</td>
<td>487</td>
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<td></td>
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<tr>
<td>5 cells</td>
<td>346</td>
<td>448</td>
<td>545</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 cells</td>
<td>408</td>
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<td></td>
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<td>582</td>
<td>582</td>
<td>582</td>
<td>590</td>
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</table>

*See drawing (a).
†See drawing (b).

Source: Varta Batteries AG, Hanover, Germany.

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(a) Cell showing dimensions used in Table 25.3.

(b) Multicell battery showing dimensions used in Table 25.3. Tolerances are 5, 3, and 3 mm for dimensions L, B, and H, respectively.
25.3.4 Special Handling and Use of Nickel-Iron Batteries

The battery should be operated in a well-ventilated area to prevent the accumulation of hydrogen. Under certain circumstances, hydrogen can be ignited by a spark to cause an explosion with a resulting fire. In multicell batteries the usual precautions in dealing with high voltages should be taken.

If the battery is to be out of service for more than a month, it should be stored in the discharged condition. It should be discharged and short-circuited, then left in that condition for the storage period. Filling caps must be kept closed. If this procedure is not followed, several cycles are required to restore the capacity upon reactivation.

Constant-voltage charging is not recommended for conventional nickel-iron batteries. It may lead to a thermal runaway condition which results in dangerous conditions and can severely damage the battery. When the battery nears full charge, the gassing reactions produce heat and the temperature rises, lowering the internal resistance and the cell EMF. Accordingly, the charge current increases under constant-voltage charge. This increased current further increases the temperature, and a vicious cycle is started. A modified constant-voltage charging with current limiting is, however, acceptable.

25.4 ADVANCED NICKEL-IRON BATTERIES

The desire to use the attractive features of the nickel-iron couple, such as ruggedness and long life, in applications requiring high-rate performance and low manufacturing costs has led to the development of advanced nickel-iron batteries with performance characteristics suitable for electric automobiles and other mobile traction applications. The capability of these batteries permits an electric vehicle a range of at least 150 km between charges, acceleration rapid enough to merge into highway traffic, and a cycling life equivalent to 10 or more years of on-the-road service. The advanced battery utilizes sintered-fiber metal (steel wool) plaques, impregnated with active material, for both the positive and the negative electrodes. Nonwoven polypropylene sheets are used as separators between electrodes. The techniques for making plaques, impregnation and activation, stacking, and assembly are all amenable to high-volume production methods similar to those used in lead-acid battery manufacture.

The battery system design incorporates an electrolyte management system to minimize the maintenance problems associated with its widespread deployment in the public sector. This system, shown schematically in Fig. 25.12, provides for semiautomatic watering of the cells by utilizing a single-point watering port. The flow of electrolyte through the cells during the charging cycle permits heat removal and effective management of gas evolved during the charge. Uniform specific gravity for all cells is ensured and specific gravity maintenance is easily achieved by use of the system.

Both the positive and the negative plates of the Westinghouse nickel-iron battery used fiber metal plaques as the substrate. Two methods of active nickel impregnation were developed and used in demonstration batteries. An electroprecipitation process (EPP), developed in the mid-1960s, demonstrated good performance, ruggedness, and long cycle life. The EPP deposits nickel hydroxide electrochemically into the porous substrate. Efficient use of the nickel material is achieved, with active material utilization of 0.14 Ah/g of total electrode. An alternate nickel electrode manufacturing process was also developed which entails the preparation of a nickel hydroxide paste that is then loaded into the fiber metal substrate by roll pasting methods. Pasted nickel electrodes demonstrated performance equivalent to EPP electrodes (0.14 Ah/g of total electrode) while demonstrating a less expensive manufacturing process. The iron electrodes were also produced by a pasting process. Iron oxide, Fe₂O₃, was paste-loaded into the fiber metal electrode substrate and then furnace-reduced in a hydrogen atmosphere. These electrodes demonstrated 0.26 Ah/g of total electrode or, better, at \( C/3 \) discharge rates.