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Introduction

Energizer® lithium iron disulfide differs from alkaline batteries in chemistry and construction. They are built in a spiral construction featuring two long, thin electrodes rolled together to form a jellyroll shape. This shape provides almost 20 times more interfacial surface area than a standard alkaline. This large interface helps to meet the power demands of many of today's devices. Lithium is the lightest, most active metal. When this powerful metal is paired with iron disulfide, this energy is available at a voltage suitable for 1.5 volt applications.

Energizer® successfully produced the first commercially available "AA" size 1.5 volt lithium battery in 1989. The 1.5 volt "AAA" size followed in 2004.

Electrodes in lithium iron disulfide batteries are isolated from one another by a highly engineered microporous polymer membrane. This membrane allows ions to move easily during normal use, but restricts this movement in certain abuse situations to ensure superior product performance and safety. Lithium iron disulfide batteries contain a nonaqueous electrolyte designed to operate even in extreme temperatures from as low as -40°C up to +60°C. They also include a resettable overcurrent safety device that protects the user by switching the battery off if it is misused in devices.



Some of the advantages of the lithium iron disulfide (LiFeS₂) system over the alkaline chemistry are:

- Direct drop-in compatibility in applications using primary 1.5 volt "AA" and "AAA" battery sizes.
- Far greater power than other primary battery types.
- Provides longer service than other primary battery types in moderate to heavy drain applications.
- Greater service advantage over other primary battery types at low temperature extremes operating at -40°C.
- Higher operating voltage and flatter discharge curve than other primary battery types.
- Superior leakage resistance compared to other primary battery types.
- Outstanding service maintenance when stored at ambient conditions.
- Considerably lighter than other battery types.
- Good service maintenance after high temperature storage up to +60°C.
- No added mercury, cadmium, or lead.

As power demands of new devices continue to increase and high drain devices become more prevalent with consumers, *Energizer*® lithium iron disulfide batteries provide the optimum performance consumers demand.

Battery Description

Cylindrical lithium iron disulfide batteries use lithium for the anode, iron disulfide for the cathode, and a lithium salt in an organic solvent blend as the electrolyte. A cutaway (fig. 1) of a typical cylindrical LiFeS₂ battery is illustrated in the following diagram:

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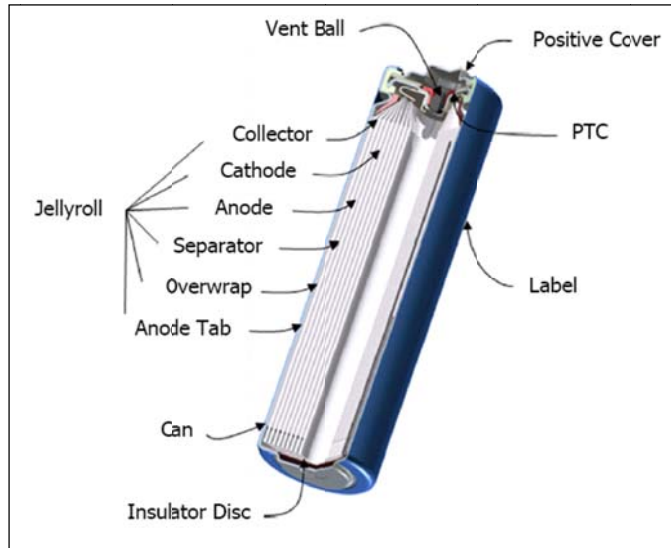
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(fig. 1) Typical cylindrical lithium iron disulfide battery

Anode - lithium metal

Cathode - iron disulfide on an aluminum foil substrate

Separator - polyolefin

Electrolyte - lithium salt / organic solvent

Jellyroll construction - spiral wound multiple layers of anode/separator/cathode material to produce a high surface area for high power cell design

Vent ball - safety mechanism that provides internal pressure release

Positive and negative contact surfaces - nickel-plated steel

Non-conductive plastic film label - electrically insulates the battery

Positive Temperature Coefficient (PTC) - over current safety device

Electrochemistry:

The term "lithium battery" refers to many different chemistries utilizing lithium as the anode but differing in cathode material, electrolyte, and construction. They may be classified in several ways, but one convenient method is by the cathode material and voltage. Using an iron disulfide cathode gives a battery with a nominal voltage of 1.5 volts. Most other lithium batteries are 3.0 volt systems using cathodes comprising either solids (manganese dioxide or carbon monofluoride) or highly toxic liquids (sulfur dioxide or thionyl chloride). Finally, lithium batteries should not be confused with lithium ion rechargeable batteries. Lithium ion batteries do not contain metallic lithium.

Under rating current drain rates (~200mA), typical of many commercial devices, the "AA" size LiFeS₂ battery has a specific energy density of ~297 Wh/kg compared to a comparable size alkaline of ~143 Wh/kg.

The characteristics that make lithium an exceptional electrode material for high energy density batteries include, low electrode potential and very high conductivity. It is soft and malleable and can be extruded into thin foils. Lithium reacts with water and for this reason must be used with a non-aqueous electrolyte.

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The choice of cathode materials is critical when considering voltage, high energy density, high rate performance, and electrolyte compatibility. Other considerations include low cost, environmentally friendly, and stability. The choice of FeS_2 as a cathode material is unique because the chemical reaction with lithium results in an open circuit voltage (OCV) of 1.8 volts. Other cathode materials combined with lithium will produce battery voltages above 2.0 volts.

Although the higher OCV of the LiFeS_2 system is 1.8 volts, the nominal or rated voltage is 1.5 volts which makes it a suitable replacement for alkaline and nickel systems. The battery voltage will drop when it is placed under load. For this reason, the higher OCV will typically not damage electronic components, but device designers should take into consideration that the OCV of fresh batteries can range from 1.79 to 1.83V. LiFeS_2 batteries fully meet the ANSI specification for a 1.5V battery. When a drain has been applied to the battery, the OCV drops dramatically and then slowly recovers with time. The OCV for a battery can be misleading. A "good" battery will generally have an OCV >1.74 volts. Any battery with an OCV <1.70 (after it has been allowed to recover) is completely discharged. Although an alkaline battery may read "good" at 1.6 volts, this reading on a LiFeS_2 battery indicates the product has been discharged.

The jellyroll battery design gives the battery excellent high rate performance. The non-aqueous electrolyte used in LiFeS_2 battery provides excellent low temperature performance.

Under high temperature operating or storage, it is not uncommon to experience some electrolyte odor. This odor is due to transmission of ethers (i.e. 1,2-dimethoxyethane and 1,3-dioxolane) through the seal. The odor threshold for these organics is on the order of a few parts per million, which does not indicate leakage. The ethers can have a noticeable odor, but the actual amount of vapors present is very low. Potential exposure is well below the American Conference of Governmental Industrial Hygienists (ACGIH) time weighted average limit and other industry standards.

The overall discharge reaction of the LiFeS_2 construction takes place in two steps. The first step: $2\text{Li} + \text{FeS}_2 \rightarrow \text{Li}_2\text{FeS}_2$. The second step follows: $2\text{Li} + \text{Li}_2\text{FeS}_2 \rightarrow \text{Fe} + 2\text{Li}_2\text{S}$. Typically the two step discharge can be seen at low drain rates of approximately ten milliamps or less and during higher drains at elevated temperatures.

The discharge characteristics of batteries can vary depending upon whether they are discharged at a constant resistance, constant current, or constant power drain. Due to the unique characteristics of the lithium chemical system, the battery will maintain a high average operating voltage compared to other systems throughout the life of the discharge. This is particularly important for constant power devices that can better take advantage of the higher voltage. As the battery voltage decreases, the current drain increases to maintain constant power to the device. Therefore, the higher voltage of lithium iron disulfide lowers the current drain on the battery and longer run times.

Temperature Effects on Performance:

Lithium iron disulfide (LiFeS_2) batteries have a much lower sensitivity to temperature compared to other chemical systems. The recommended operating temperature range is -40°C to $+60^\circ\text{C}$ (-40°F to $+140^\circ\text{F}$). As with all battery systems, service life is reduced as the discharge temperature is lowered below room temperature (fig. 2). Batteries generate power through chemical reactions and these typically run much more slowly at lower temperatures. However, even at -40°C , the LiFeS_2 batteries perform well at the rating drain 200 mA. LiFeS_2 batteries can deliver approximately full rated capacity at -40°C if they are discharged at 25 mA. Thus, at these rates, the batteries give comparable performance over the entire 100°C operating range.

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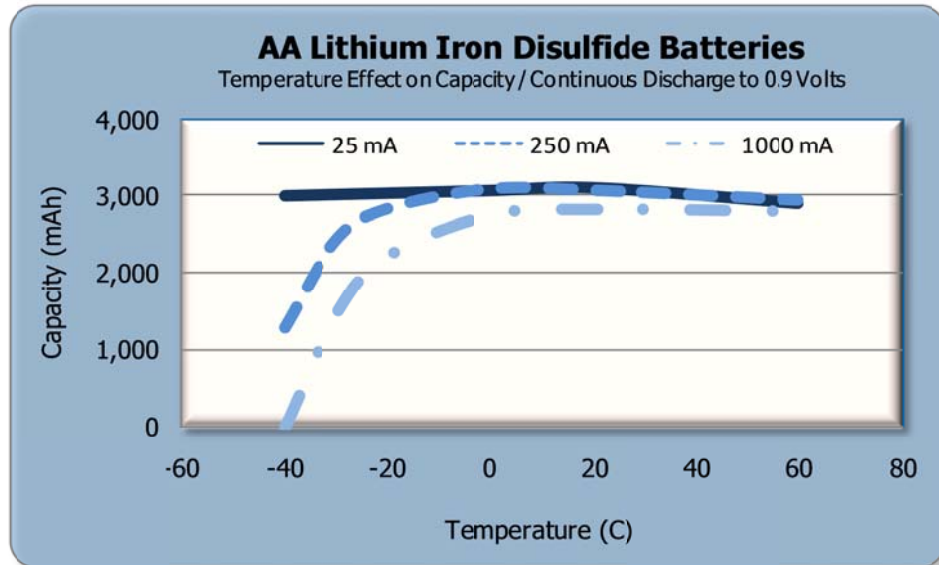
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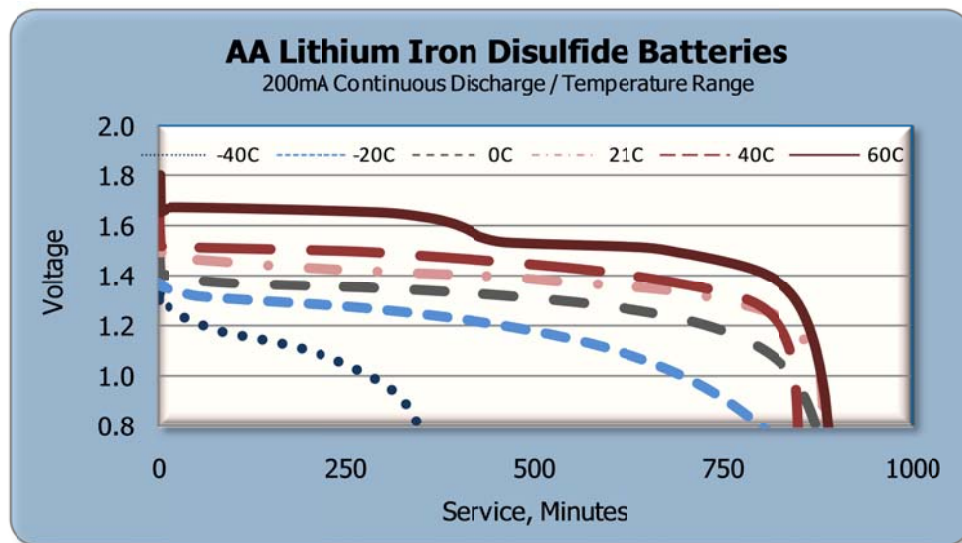
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(fig. 2) Temperature Effect on Capacity

Cold temperatures also lower the operating voltage thereby reducing the energy output (fig 3). Battery capacity is not lost due to cold temperature use, rather it is more difficult to access the battery's full potential due to the slowing of the electrochemical reactions, reducing capacity at high drain rates.



(fig. 3) Temperature Effect on Performance

When comparing cold temperature performance of the LiFeS_2 battery versus an alkaline based aqueous system, the LiFeS_2 system is affected much less across a range of drain rates (fig 4) and operates at temperatures where alkaline batteries do not run at all. This is due to the use of a non-aqueous electrolyte and the high surface area jellyroll construction. In particular, Energizer's patented electrolyte has the unique property of actually increasing in conductivity as the temperature drops, in contrast to electrolytes used in other lithium batteries.

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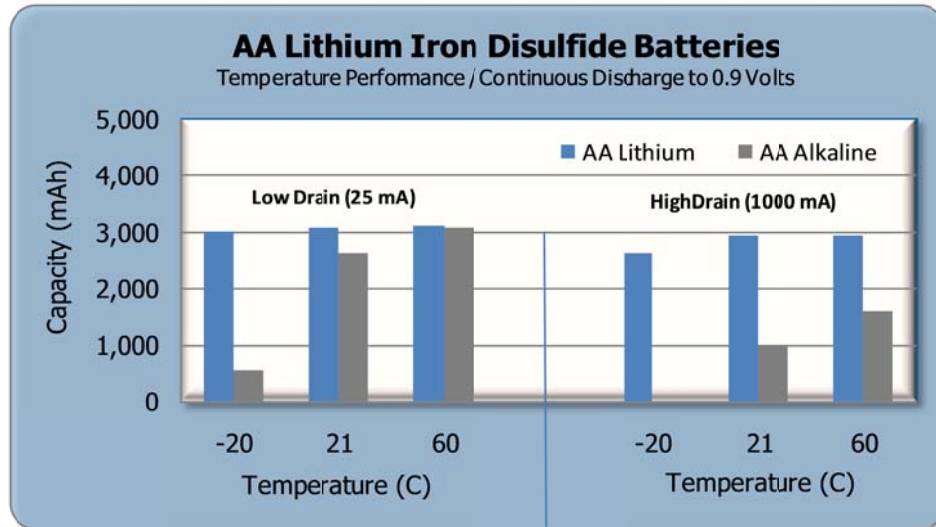
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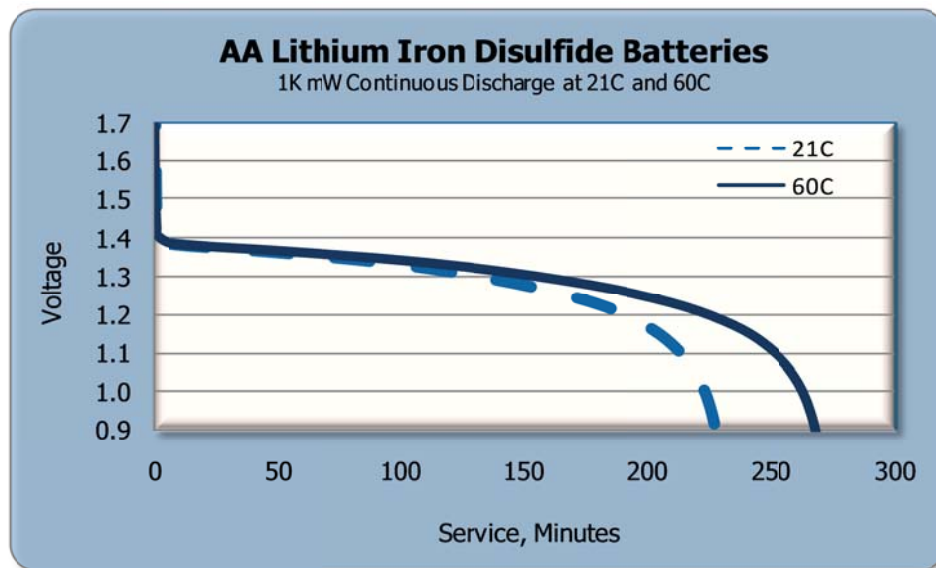
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(fig. 4) Temperature Effect on Performance Versus Alkaline

Conversely, warm temperatures can boost battery performance in very high drain continuous applications that increase the battery temperature (fig 5).



(fig. 5) Elevated Temperature Effect on Performance

In some applications there may be further limits on the maximum discharge temperature due to current limiting safety features of the battery. The LiFeS₂ battery utilizes a PTC (positive temperature coefficient over current safety device) that is designed to reversibly shut down the battery at high temperatures. Both ambient temperature and the internal battery heating that occurs during discharge will affect the operation of the PTC.

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The higher the rate of discharge (a heavy drain or load on the battery), the more heat is generated that could cause the PTC to activate. In low to moderate drain applications, less than 500 mA, the heat dissipates and should not activate the PTC. However, a high ambient temperature combined with a high drain application increases the likelihood of PTC activation. Moreover, many applications use power intermittently and this can greatly mitigate any temperature rise and prevent PTC activation. While PTC activation in these rare scenarios may be a nuisance, the PTC is critical to battery safety. The batteries and device should once again perform normally once the battery has time to cool down.

Device manufacturers must consider all of the following that can affect internal heating of LiFeS₂ batteries during discharge

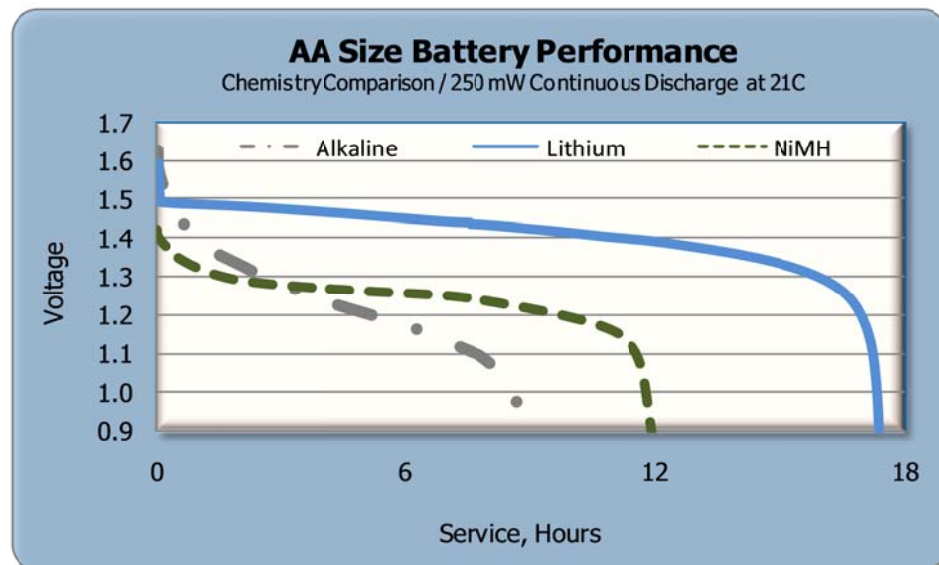
- Surrounding air temperature
- Thermal insulating properties of the battery container
- Heat generated by equipment components
- Cumulative heating effects of multiple batteries
- Discharge rate(s) and duration(s)
- Frequency and length of rest periods

Comparison to other Chemical Systems:

Lithium iron disulfide batteries have a higher operating voltage than alkaline and rechargeable nickel metal hydride (NiMH) batteries and flatter discharge profile versus alkaline. These characteristics result in higher energy density (Wh/L) and specific energy (Wh/kg), especially in heavier drain applications where the operating voltage differences are the greatest.

The flatter discharge curve allows for consistent performance throughout the life of the battery. The performance advantages of lithium over alkaline increases dramatically as drain rates increase due to the jellyroll construction and better high rate efficiency.

The following chart (fig. 6) shows the relative constant power performance of an AA size battery for the lithium, alkaline and NiMH chemistries.



(fig. 6) Relative Constant Power Performance of an AA Size Battery (different chemistries)

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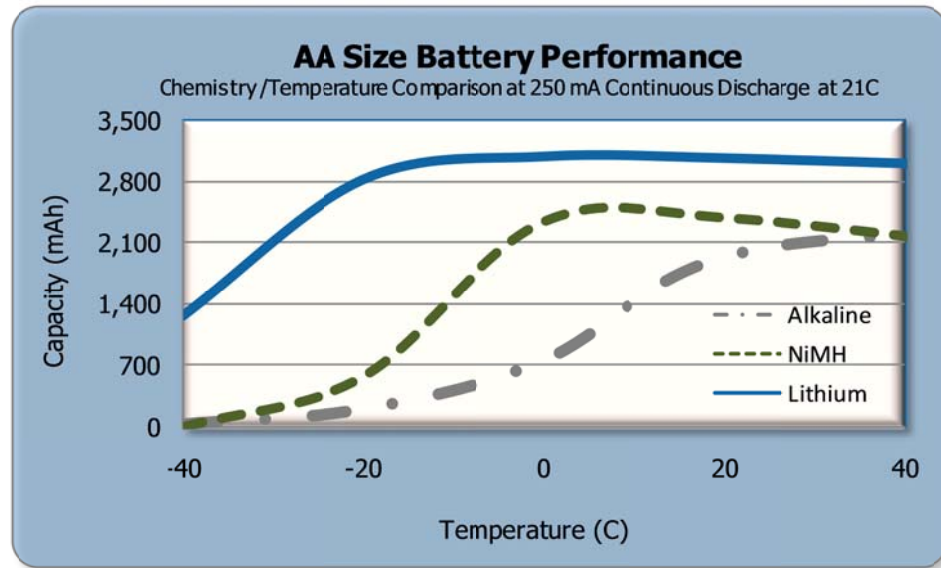
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Lithium iron disulfide batteries are suitable for use across a broad temperature range. While at elevated temperatures, all chemistries show minimal change in performance versus ambient. At low temperatures, the lithium battery offers more performance than alkaline or NiMH chemistries. The following graph (fig. 7) shows the impact of temperature on AA size lithium, alkaline and NiMH under a 250 mA drain rate to a 0.9 volt cutoff.



(fig. 7) Impact of Temperature on AA Size Lithium, Alkaline and NiMH

Additional performance comparisons can be found on the [individual datasheets listed on the Technical Information website](#). Additional LiFeS₂ advantages are summarized in the following table:

Characteristics	Lithium	Alkaline	NiMH
Cold Temp Performance	Superior	Good	Superior
Weight	33% < Alkaline	33% > Lithium	33% > Alkaline
Shelf Life	10 to 15 Years	5 to 7 Years	3 to 5 Years
Leakage Resistance	Superior	Good	Good
Discharge Curve	Flat	Sloping	Flat
High Rate Capability	Superior	Fair	Superior

The most reliable method to determine the battery service life for a particular application is to test the batteries in the device. When this is not practical, simulation testing can be done if the following are known: operating voltage, current or power drain, duty cycle (time that device is on / off) and end point voltage of the device. Once these parameters are known, approximate battery service life can be determined.

Internal Resistance and Impedance:

Battery internal resistance (IR) and impedance are unfortunately terms that are often used in a variety of ways in the battery industry. This section addresses some of Energizer's AA size lithium iron disulfide IR and impedance measurement techniques. It is meant to provide guidance to battery designers. A detailed explanation of the precise cause behind the factors that control battery IR and impedance is beyond the scope of this document.

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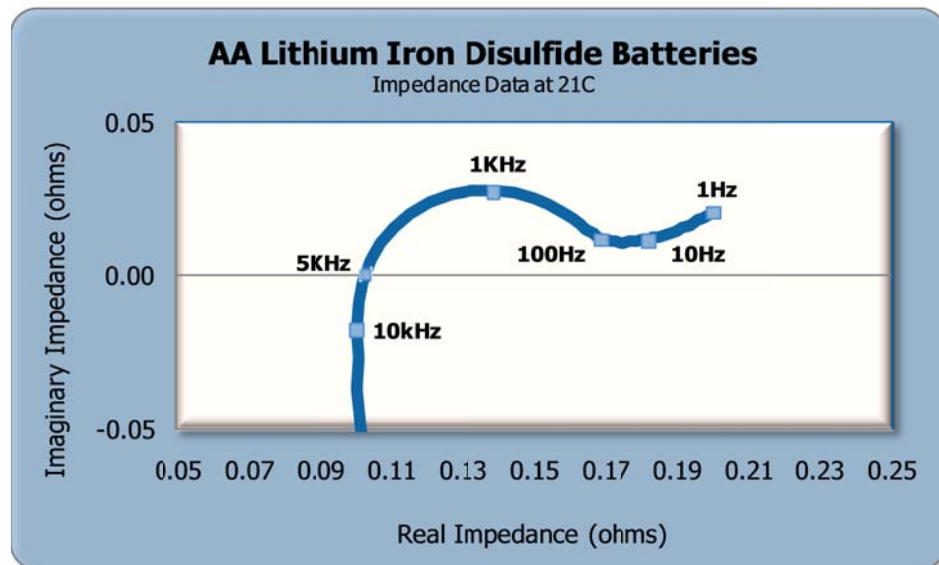
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A common method of measuring battery impedance is to use an AC measurement technique over a wide range of frequencies, such as 50 kHz to 1 Hz or less. At very high frequencies, only the true IR is observed. As the frequency is decreased, other processes involving the chemistry inside the battery during discharge contribute to the impedance. As a result, the measured impedances always increase as the AC frequency is decreased. A typical impedance scan for the AA size lithium iron disulfide battery is shown in (fig. 8). The true battery IR is given by the resistance at high frequency where the data meets the x-axis. Energizer typically uses a 10 kHz impedance to measure the true IR of AA size lithium iron disulfide batteries. Typical values are 100 mΩ. Relative to other battery chemistries, the AA size lithium iron disulfide battery has the lowest IR of any lithium battery and compares favorably to primary aqueous batteries.



(fig. 8) Complex plane impedance scan for a typical AA size lithium iron disulfide battery

In terms of effect on the battery, the true IR is more important than the impedance at low frequencies. The true IR effectively acts as a resistor in series with the device that lowers operating voltage acting as an additional load on the circuit. The impedance values recorded at lower frequencies can also influence battery behavior, but generally not to the same extent as the true IR.

Another method used to estimate true IR uses a current interrupt technique (CIT), whereby the rapid change in battery voltage during discharge is periodically and briefly interrupted to estimate the battery IR. This has the advantage of measuring the battery IR under realistic drain rates and also enables one to measure the change in battery IR during discharge. The following graph (fig. 9) shows that there is very little change in battery IR during discharge and in fact it actually improves slightly.

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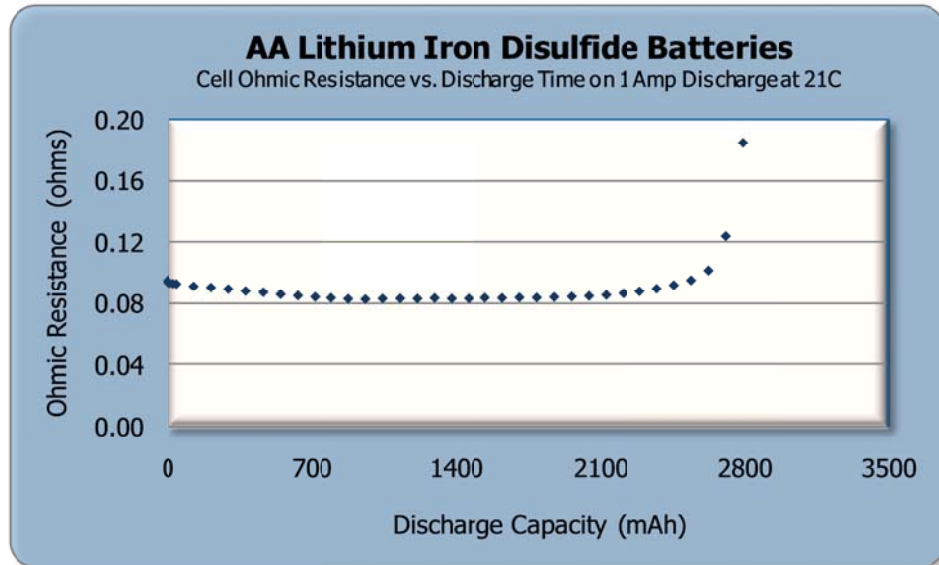
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(fig. 9) True IR of a typical AA size lithium iron disulfide battery during 1 amp discharge. Comparison of measurements using high frequency impedance scans and a CIT method.

True IR is not adversely affected by temperature (almost no change between -20 and 40°C), discharge current, depth of discharge, battery age or storage at elevated temperatures. While high temperature storage can increase the impedance at low frequencies (longer timescale), this has little if any impact on battery performance.

The resistance to current flow that a battery exhibits can depend on the current drain being applied and especially on the time scale of the measurement. The methods described above measure battery IR over a very short time scale. In actual device applications, various polarization effects occurring over longer times will reduce the battery's operating voltage and appear as resistance contributors. From a design engineers' point of view, a more important metric of the battery's performance may be the *effective* IR which is the impedance during actual usage.

Typically, effective IR is greater than the true IR. However, since the effective IR depends on the load and timescale, any measurement that relies upon the OCV of the battery prior to a test should not be used. A commonly used method whereby the resistance is calculated as shown below must not be used with AA size lithium iron disulfide batteries as the values are much higher than the real values. This is due to the initial OCV of AA size lithium iron disulfide batteries being higher than the OCV of the chemistry that actually controls the battery's discharge performance.

$$\text{Effective IR} = (\text{OCV} - \text{CCV}) / \text{Current Applied (not valid for lithium iron disulfide batteries)}$$

Effective IR can be calculated by using a double current pulse CCV measurement whereby the system first applies a low current drain pulse to reduce the OCV and then applies a heavier pulse. The effective IR at the higher drain rate can then be calculated by the voltage difference between the two pulses. The timing of the pulses should reflect the timescale of interest to the application. For example, apply a 10 mA pulse for 50 ms followed by a 500 mA pulse for 100 ms (fig. 10). Values of effective battery IR measured using this regime are about 100 mΩ.

$$\text{Effective IR} = (\text{CCV}_1 - \text{CCV}_2) / (\text{Current}_2 - \text{Current}_1)$$

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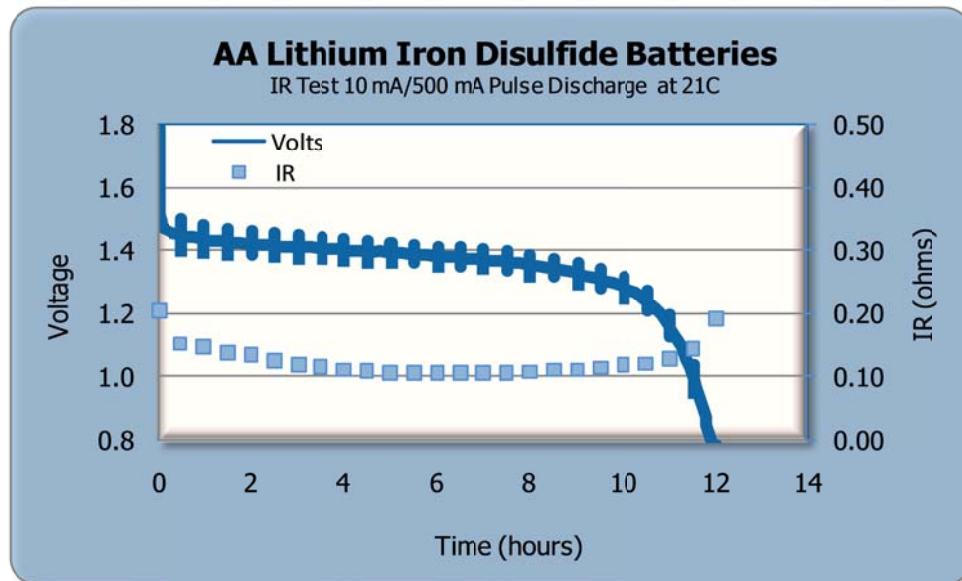
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(fig. 10) IR of a typical AA size lithium iron disulfide battery during discharge.

Again, caution must be exercised in comparing true IR values to effective IR readings or those obtained using other measurement methods. In particular, impedance measurements at 1kHz or resistance values based on OCV-CCV differences typically overestimate the IR for lithium iron disulfide batteries.

Overall, the lithium iron disulfide battery IR changes very little with age, discharge rate, depth of discharge and temperatures of -20 to 40°C. While impedance at lower frequencies can increase during aging, this has very little effect on the impedance of the battery when it is subsequently placed under load.

Capacity:

Battery capacity is typically expressed in terms of milli-Amp hours (mAh). This is an indication of how long a battery will provide service at a specific drain rate to a specific cutoff voltage. For example, the following discharge curve (fig. 11) is for the AA size lithium iron disulfide battery being discharged at 200 mA to a 0.9 volt cutoff.

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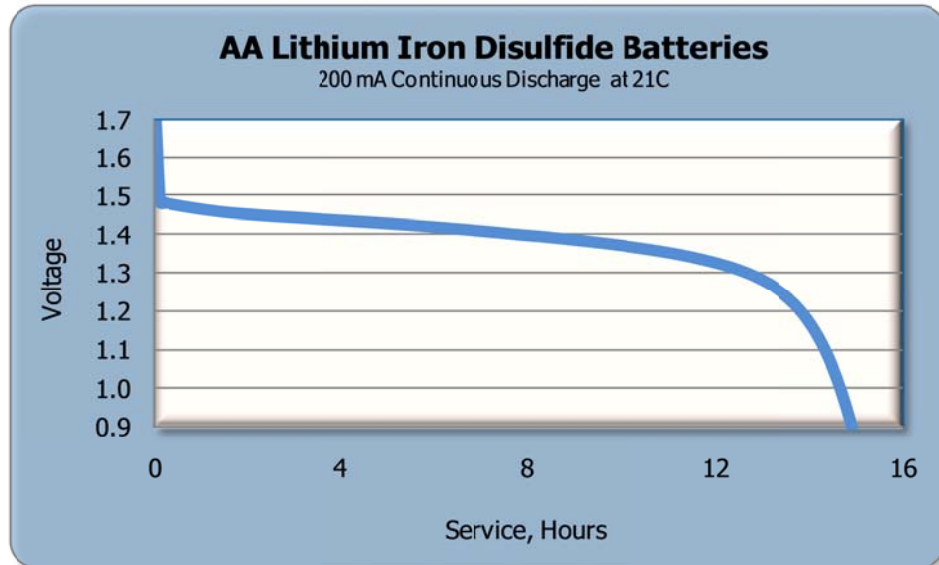
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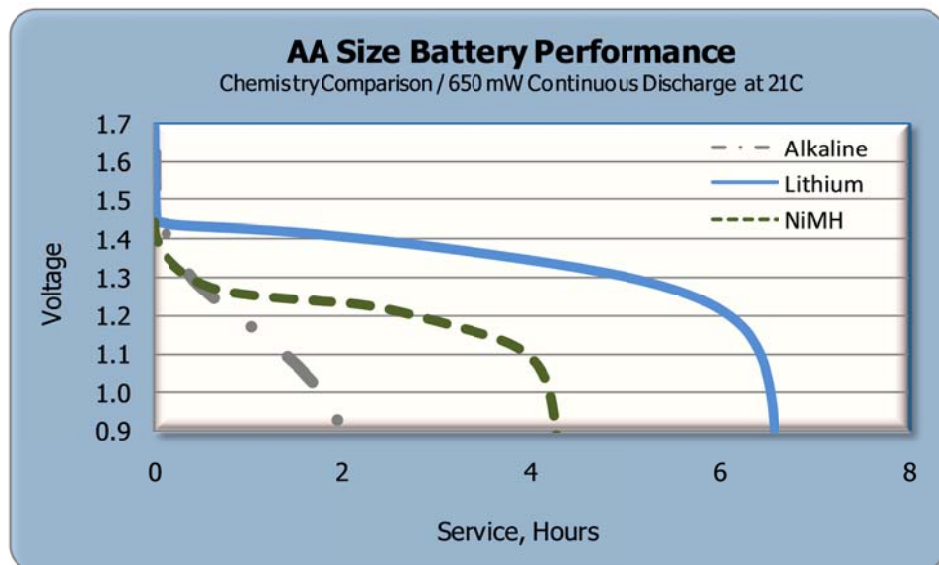
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(fig. 11) 200 mA Continuous Discharge

The available capacity can then be calculated by multiplying the drain rate (mA) by the hours to the cutoff voltage. For example, this AA battery would have a capacity of (200 mA X 15 hours) 3000 mAh at a 200 mA drain to a 0.9 volt cutoff.

The mAh capacity of lithium iron disulfide batteries will vary with the drain rate and the cutoff voltage. Due to the jellyroll construction and multiple layers of active material, the lithium iron disulfide battery is extremely efficient across multiple drains and is much less sensitive to both the drain rate and voltage cut than alkaline batteries. The flat discharge profile and high operating voltage of lithium iron disulfide allow for longer, consistent run times in high drain / high power devices as shown below (fig. 12).



(fig. 12) Chemistry Discharge Curve Characteristics

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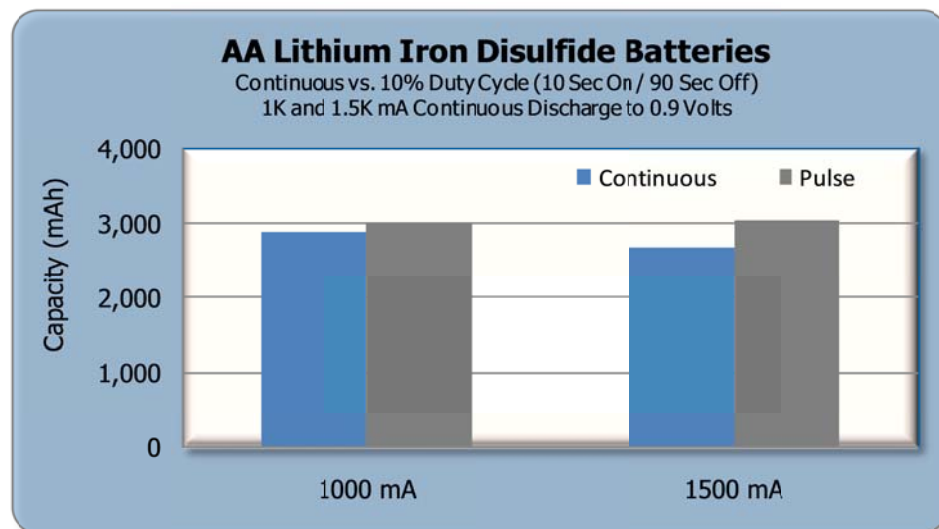
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The application cutoff voltage will also impact the amount of service delivered by the battery. A high cutoff voltage will result in leaving more of the battery's capacity unused. To maximize usage of the available capacity, it is recommended that devices should be designed with a voltage cutoff of 0.8 volts per battery. At this point, a majority of the battery's usable capacity has been removed. However, lithium iron disulfide operates at a higher voltage and is well suited for high cutoff devices. Ideally, to avoid deep discharging batteries, one should not discharge them below 0.5 volts.

In high drain pulse applications, the duty cycle can impact battery efficiency. A very light duty cycle will typically allow the battery more time to recover and extend service compared to a continuous drain. The amount of additional service will depend on the drain rate, and the duty cycle (ON time and OFF time of the pulse). Due to LiFeS_2 high rate capability, the effect of intermittent duty cycles is relatively modest compared to other chemical systems. The modest effect of duty cycle on capacity delivered can be seen in the graph (fig. 13).



(fig. 13) Effect of Duty Cycle

The maximum recommended pulse drain for LiFeS_2 is based on the battery's ability to deliver high current over a range of 100 milliseconds to 2 seconds. The "AA" size can deliver up to a 3 Amp pulse. At these rates, it is important to consider heat generation by adjacent batteries and consider the affect on the PTC. This part will change from low to high impedance when activated during abusive conditions that cause a temperature rise. Actual testing is needed to determine the amount of additional service expected in pulse applications since there is no simple equation to accurately calculate the impact of duty cycle on service.

In ultra low drain applications (i.e. currents in micro amps, where the battery is expected to run several months), the discharge curve has a distinct two stage profile. The first step occurs at slightly higher voltage (nominally 1.79V @ 21° C, dictated by thermodynamics) that increases with temperature and is nearly independent of depth of discharge. The second step occurs at a slightly lower voltage (nominally 1.7V @ 21° C) that decreases with temperature and is a function of depth of discharge. At low drain rates, the lithium iron disulfide battery will provide approximately full rated capacity over its lifetime.

The two stage discharge profile can benefit the device manufacturer as a method to implement fuel gauging in low drain applications. The discharge curve below shows the distinct plateaus where voltage, impedance, coulomb counting or combination of these methods could be used to determine depth of discharge needed to calculate remaining battery life. It should be noted that the lithium iron disulfide battery has a steep voltage drop off at the end of life (fig. 14). Please contact your *Energizer*® sales representative for further information on this subject.

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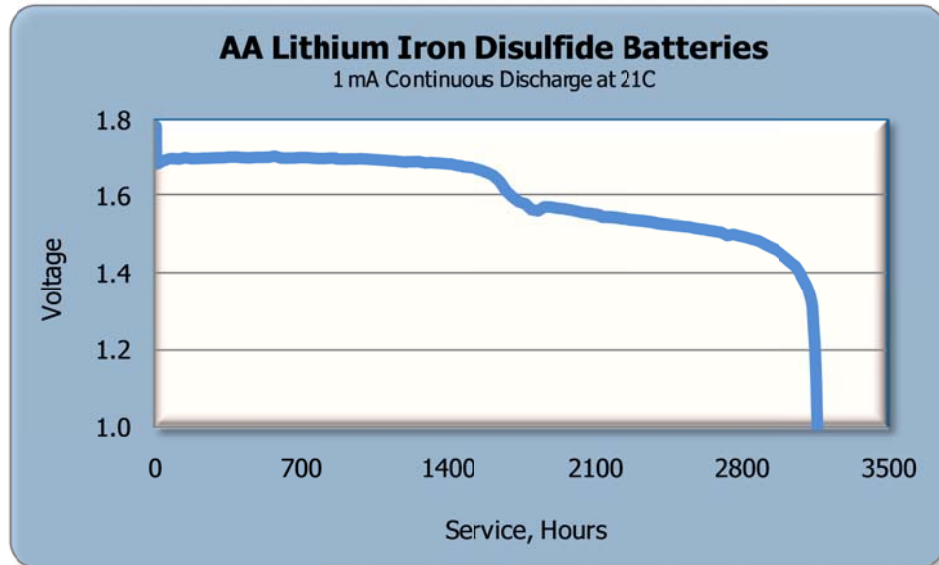
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(fig. 14) Two Stage Discharge

Shelf Life:

Shelf life can be defined as the time at which a battery will deliver approximately 80% of its original capacity (fig. 15). Predicting battery shelf life is done in various ways. Typically, elevated temperature storage is used to accelerate those processes that cause degradation. This method is convenient, but is not always reliable because increasing cell temperature can introduce a new mode of degradation that is not present in batteries stored at lower temperatures. This could yield an underestimate of the true shelf life. Another method for predicting shelf life is microcalorimetry that measures the heat output from batteries and provides an estimate of the chemical changes occurring inside the battery. *Energizer®* has tested LiFeS_2 cells using all of these methods.

Lithium iron disulfide batteries will lose approximately 0.6 % of their capacity per year when stored at room temperature, 21°C. Because of the very low level of impurities in the materials used and the high degree of seal effectiveness used with lithium batteries, the shelf life after high temperature storage is far better compared to aqueous systems. The recommended storage temperature for lithium batteries is -40°C to 60°C. Exposing lithium batteries to temperatures above 60°C can cause the insulating label to shrink and expose the battery's steel can to potential external short circuits.

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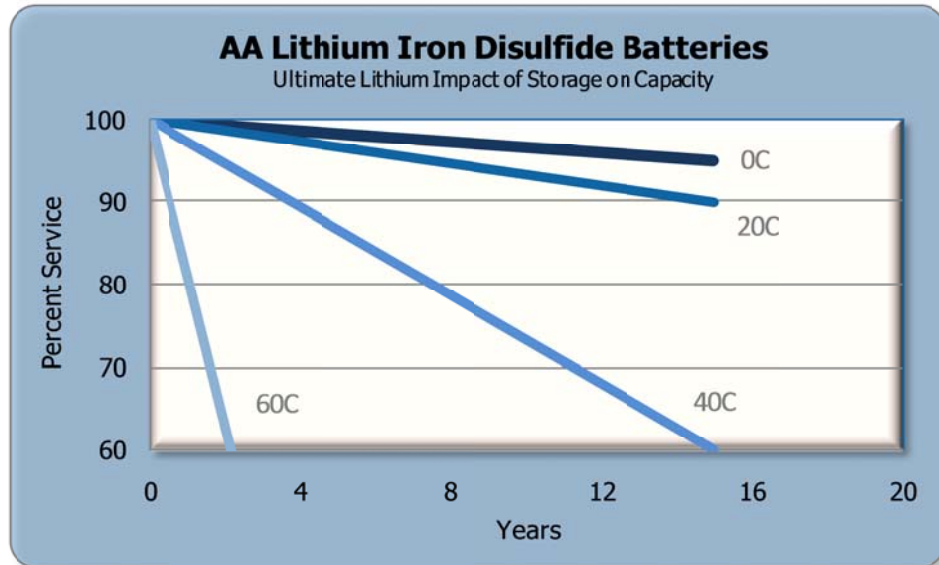
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(fig. 15) Impact of storage

Testing / Care / Warnings:

The lithium iron disulfide construction incorporates many safety features and extensive quality checks during manufacture on each and every battery. The design includes two safety devices to provide protection against abusive conditions such as short circuit, charging, forced discharge and overheating. These two safety devices are a resettable thermal switch or PTC (Positive Thermal Coefficient) and a pressure relief vent. The PTC protects against electrical abuse scenarios by limiting the current when the PTC temperature exceeds 85°C. As the battery heats during abuse, the resistance of the PTC rapidly increases and significantly limits the amount of current flowing through the battery, thus allowing the battery to cool. When the PTC cools to below the activation temperature, its resistance returns to a normal level allowing normal battery use. The PTC is extremely effective in safely handling electrical abuse conditions.

Below is an example of an "AA" size lithium iron disulfide battery subjected to a direct short showing that the PTC reduces the current within seconds to a safe level (fig 16).

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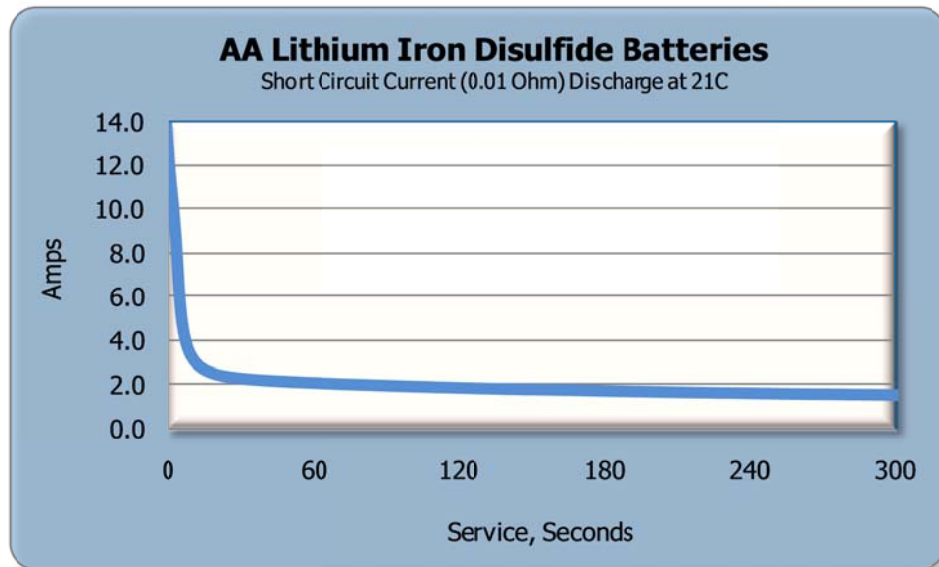
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(fig. 16) Short Circuit Current

The PTC can rarely activate during non-abuse conditions, depending on how quickly the battery can dissipate heat generated from discharge. A combination of high discharge rate (which generates more heat) and high ambient temperature can cause the PTC to limit current.

In addition, insulation within the battery compartment, proximity to adjacent batteries and neighboring electronic components can generate or retain additional heat. Intermittency, which is common for many applications, can greatly alleviate the internal heating affect.

During use, all batteries generate heat. On light loads the heat dissipates and is not noticeable, but on heavy drains the battery may become noticeably warm to the touch. This is expected and normal and also true of alkaline batteries. Extended exposure to heat may also cause shrinkage of the label. Label shrinkage can occur when the battery is exposed to extreme conditions and is not indicative of battery failure.

The vent mechanism operates at $\sim 150^{\circ}\text{C}$ and allows a controlled release of pressure thus preventing the battery from exploding in the event of abuse conditions, such as internal short circuits. This venting also limits the current the battery can carry and prevents additional heat generation.

The maximum continuous current drain for the "AA" size is 2.0 amps. Higher drain rates can be used for short periods of time. Because of the number of other variables involved, it is difficult to predict in advance whether lithium iron disulfide batteries can operate under extreme load conditions. In order to determine the highest pulse rate achievable, testing the batteries in the device under worst case conditions is recommended. While the PTC does impose some limitations on high rate applications for which lithium iron disulfide batteries are suitable, it is a critical element in ensuring that the battery is safe and protects the battery, the equipment and the user.

Although the safety mechanisms described above will limit the potential for battery failure due to abuse, there are additional handling considerations for the proper safe use of lithium iron disulfide batteries:

- Avoid potting or encapsulation as this obstructs the pressure relief vent. The vent is required to prevent excessive heat or pressure buildup if the battery is exposed to abusive conditions.
- Avoid charging as lithium iron disulfide batteries are not designed to be recharged.
- Use of pressure contact for batteries is recommended in the device compartment. If welded connections are needed, they should be made to the nickel-plated positive cap and the nickel-plated bottom using a [capacitor discharge welder](#). Solder connections should be avoided because of the intense heat that needs to be applied to the battery.

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- Battery labels insulate the battery to reduce the incidence of a potential direct short circuit or inadvertent charging. Battery compartment contacts and welded tab connections must not have sharp edges/burrs that could cut through the battery label especially adjacent to the positive terminal.
- Do not open battery, dispose of in fire, heat above 100°C (212°F), expose contents to water, recharge, install backwards, mix with used or other battery types. These conditions may cause personal injury.
- There is no risk of hydrogen generation with lithium iron disulfide batteries and they can be used safely in water tight applications.
- Lithium iron disulfide batteries can safely undergo ethylene oxide or gamma radiation sterilization.

For additional information it is imperative to read the section "[Design and Safety Considerations](#)" to assure that other safety considerations are not overlooked.

Disposal and Shipping:

Disposal:

Energizer® lithium iron disulfide batteries are United States Resource Conservation and Recovery Act (RCRA) non-hazardous waste.

Waste lithium iron disulfide batteries meet the United States Federal definition of a solid waste per 40 Code of Federal Regulations (CFR) 261.2. As such, the generator must make certain determinations relative to the waste material. Waste lithium iron disulfide batteries do not fall under any of the specific United States Federal RCRA F, K, P, or U lists, nor do any states specifically regulate this type of waste, to our knowledge.

This leads us to the RCRA characteristic waste criteria. Toxicity Characteristic Leaching Procedure (TCLP) listed materials are not used as battery components and may only be present in trace quantities in some of the battery parts. Based on our knowledge of the battery and battery raw materials, waste lithium iron disulfide batteries are not RCRA toxic. Only the characteristics of ignitability, corrosivity, and reactivity remain as possible classifications.

The batteries are solid, not liquid, which precludes their being a corrosive waste, since corrosive waste must be liquid by definition. As an inert solid, flash point is not an appropriate test for ignitability. Our batteries are a safe consumer product and, under standard temperature and pressure conditions, will not cause fire through friction, absorption of moisture, or spontaneous chemical changes. Since iron disulfide is one of the primary electrode materials of the lithium iron disulfide, clearly the batteries do contain sulfides. The amount of reactive or releasable sulfide is substantially below the regulatory limit as established by the Environmental Protection Agency (EPA) Manual SW-846, [Test Methods for Evaluating Solid Waste](#). The batteries contain no cyanides and they do not meet any other reactivity criteria, including the criterion "reacts violently with water." An intact scrap battery will not react in that manner.

To meet United States Department of Transportation (DOT) requirements, scrap lithium iron disulfide batteries are packaged per the following from 49 CFR 173.185 (h):

- 1) The limit of 1 grams of lithium per cell is not exceeded.
- 2) External short circuits are effectively prevented.
- 3) Strong outer packaging is used conforming to part 173.24 and 173.24 (a).

Since scrap lithium iron disulfide batteries meet the requirements of 49 CFR 173.185 (h), they are not subject to the further requirements of 49 CFR 173.185.

United States Federal hazardous waste regulations are specific about relating waste determination to the waste as generated. As generated, scrap lithium iron disulfide batteries are not a specifically listed waste stream and they do not meet the criteria for ignitable, corrosive, reactive, or toxic wastes. Scrap lithium iron disulfide batteries are not hazardous waste and they are not regulated by DOT as hazardous materials.

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Other nations and some US states may regulate waste based on additional criteria or different test protocols. The status of scrap lithium iron disulfide batteries should be confirmed in the nation or US state(s) where disposal occurs.

EU Battery Directive:

In September 2006, the new EU Battery Directive (2006/66/EC) was published in the European Official Journal. The directive details are summarized and split into four parts (Registration and Financing, Prohibition of Ingredients, Collection and Recycling Targets and Marking) below.

Registration and Financing

- Entities (defined as producers in 2006/66/EC) placing portable batteries onto the market must register within each member state with official bodies (to be determined and agreed by national laws/decrees).
- The entities will also have to join a collection and recycling organization (CRO) and pay a fee based on the volume of batteries they place into the member state.
- The collection and recycling costs shall not be shown separately to the end-user at the time of sale.

Prohibition of Ingredients

- Batteries shall not contain more than 0.0005% (5 parts per million or ppm) mercury by weight. Button cells may contain up to 2% mercury by weight.
- Batteries shall not contain more than 0.002% (20 ppm) cadmium by weight. Batteries intended for use in the following applications are exempt from the cadmium requirement:
 - o Emergency and alarm systems;
 - o Emergency lighting;
 - o Medical equipment; and
 - o Cordless power tools.

Collection and Recycling Targets

- All portable batteries throughout European Member States are subject to collection.
- Collection targets have been established as
 - o 25% of the batteries sold by 2012
 - o 45% of the batteries sold by 2016.
- The recycling efficiency of batteries collected shall be
 - o 65% for lead acid batteries;
 - o 75% for nickel cadmium batteries; and
 - o 50% for all other types.

The methodology for calculating recycling efficiency is to be decided no later than March 2010.

Marking

- All portable batteries placed onto the market after 26 September 2008 shall be marked with the crossed-out dustbin symbol.



- The dustbin symbol shall cover at least 3% of the area of the largest side of the battery, accumulator or battery pack up to a maximum size of 5 x 5 cm. For cylindrical cells, the symbol shall cover at least 1.5% of the surface area with a maximum size of 5 x 5 cm.

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- Small batteries (AAA size and smaller), where the symbol would be smaller than 0.5 x 0.5 cm need not be marked, but a dustbin symbol measuring at least 1 x 1 cm shall be printed on the packaging.
- Batteries with more than 0.0005% (5 ppm) mercury, 0.004% (40 ppm) lead or 0.002% (20 ppm) cadmium must also be marked with the chemical symbol (Hg for mercury, Pb for lead, Cd for cadmium) below the dustbin symbol.



Hg



Pb



Cd

- For electronic devices, the crossed-out dustbin symbol is already in place for the WEEE directive (2002/96/EC). For appliances containing AAA or smaller batteries, there will be a need for including the battery dustbin (and chemicals wherever applicable):
 - o On the packaging of the appliance;
 - o Inside the instructions / manual; or
 - o On the appliance itself.
- Batteries shall also be marked with the capacity (small batteries shall contain the capacity on the packaging) by 26 September, 2009. The details of how to measure capacity are under development but shall be completed no later than 26 March, 2009. Most *Energizer*® batteries intended for the EU market shall contain the necessary markings but care must be taken to ensure batteries packaged with equipment contain the appropriate markings if the dustbin is not marked on the battery (AAA and smaller) . There are additional minor requirements dealing with explanation of the markings for batteries sold in Europe.

For additional questions or concerns:

- Refer to the battery directive 2006/66/EC ;
- Contact the European Portable Battery Association (EPBA)

EPBA
204, avenue Marcel Thiry
1200 Brussels, Belgium
Telephone: +32/2 774 96 02
Fax +32/2 774 96 90
Email: epba@kelleneurope.com

Position papers are also regularly posted on the EPBA web site at: <http://www.epbaeurope.net>; or
Contact your authorized *Energizer*® distributor.

Shipping:

The rules governing the transportation of lithium batteries are divided into slightly differing regulations in the United States and outside the United States. Each set of rules is shown separately below for both battery transportation and for batteries packed with or inside equipment.

UPDATE The U.S. Department of Transportation (DOT) will be publishing a Supplemental Notice of Proposed Rulemaking – not a final effective rule – in December, 2011 with a final rule scheduled for some time in 2012. This Supplemental Notice of Proposed Rulemaking replaces the proposal dated January 11, 2010.

This guidance document is meant to cover expected situations for shipments of Energizer lithium batteries only. For special circumstances, please contact your authorized Energizer distributor.

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Lithium batteries identified as being defective for safety reasons, that have been damaged or have the potential of producing a dangerous evolution of heat, fire or short circuit are forbidden for transport (e.g. those being returned to the manufacturer for safety reasons).

For all shipments, it is required that any person preparing or offering lithium cells or batteries for transport receive adequate instruction on these requirements commensurate with their responsibilities.

Within, To and From the United States

Batteries Only - Surface and Air Transportation (49 CFR 172.102.188)

To ship lithium batteries by any method (rail, truck, sea vessel, air) within, to and from the United States, the shipments must meet the criteria shown below.

- Batteries must be packaged in a manner to prevent short circuits and separated so that electrically active terminals cannot come into contact with each other.
- The gross weight of the shippable container shall not exceed 30 kg.
- The shippable container must be capable of passing a 1.2 m. drop test in any orientation without spillage of the contents of the packaging, damage to the batteries inside or shifting of the contents that could lead to short circuit.
- The shippable container must be marked "PRIMARY LITHIUM BATTERIES – FORBIDDEN FOR TRANSPORT ABOARD PASSENGER AIRCRAFT" or "LITHIUM METAL BATTERIES – FORBIDDEN FOR TRANSPORT ABOARD PASSENGER AIRCRAFT". This marking must be a background of contrasting color and the letters must be at least 6 mm in height.
- The shippable container must be marked to indicate lithium batteries are present and that special procedures should be followed if the package is damaged.

To meet the marking requirements addressed above, Energizer marks packages with the following label.



For customers re-shipping batteries, the CHEMTREC information may not be used without a subscription from CHEMTREC.

Customers may also use the red and white bordered label shown on page 6 of this document, in place of the yellow label above, provided the statement "PRIMARY LITHIUM BATTERIES – FORBIDDEN FOR TRANSPORT ABOARD PASSENGER AIRCRAFT" is marked on the same face of the packaging with the red-bordered label. The font-size requirements listed above would still apply.

- Each shipment must be accompanied by documentation that includes the following statement:

"This shipment contains Primary Lithium batteries. Do not damage or mishandle the packages. If package is damaged, flammability hazard may exist; batteries must be quarantined, inspected, and repacked."

- The cell or battery must be of the type proven to meet the requirements of each test in the United Nations (UN) Manual of Tests and Criteria, Part III, Sub-Section 38.3 Lithium Batteries).

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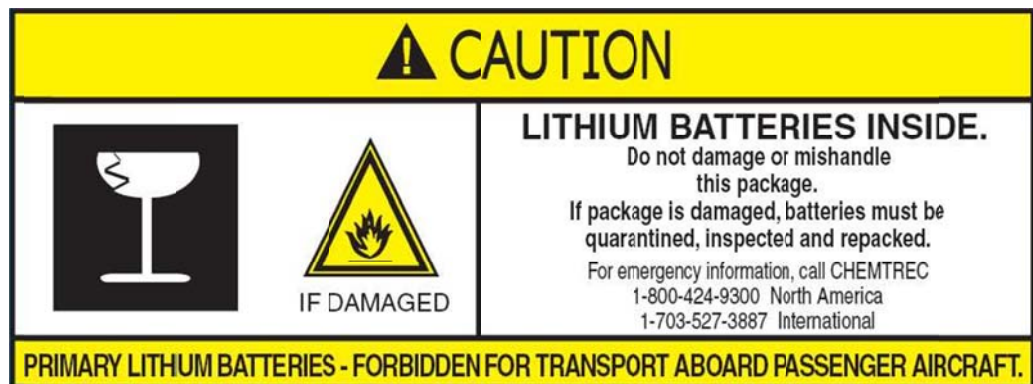
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Batteries Contained In or Packed With Equipment, Surface and Air Transportation (49 CFR 172.102.188) and (49 CFR 172.102.A101)

- Batteries must be packaged in a manner to prevent short circuits and separated so that electrically active terminals cannot come into contact with each other.
- The shippable container must be marked "PRIMARY LITHIUM BATTERIES – FORBIDDEN FOR TRANSPORT ABOARD PASSENGER AIRCRAFT" or "LITHIUM METAL BATTERIES – FORBIDDEN FOR TRANSPORT ABOARD PASSENGER AIRCRAFT". This marking must be a background of contrasting color and the letters must be at least 6 mm in height.
- The shippable container must be marked to indicate lithium batteries are present and that special procedures should be followed if the package is damaged.

To meet the requirements addressed above, Energizer marks packages with the following label.



While the CHEMTREC information is not required for batteries packaged with or in equipment, Energizer uses the same label for all shipments (batteries and batteries with or in equipment.) For customers re-shipping batteries with or in equipment, this CHEMTREC information may not be used without a subscription from CHEMTREC.

Customers may also use the red and white bordered label shown on page 6 of this document, in place of the yellow label above, provided the statement "PRIMARY LITHIUM BATTERIES – FORBIDDEN FOR TRANSPORT ABOARD PASSENGER AIRCRAFT" is marked on the same face of the packaging with the red-bordered label. The font-size requirements listed above would still apply.

- Each shipment must be accompanied by documentation that includes the following statement:

"This shipment contains Primary Lithium batteries. Do not damage or mishandle the packages. If package is damaged, flammability hazard may exist; batteries must be quarantined, inspected, and repacked."

- There is no maximum packaging gross weight.
- For air shipments only:
 - o The package shall contain no more than the number of lithium batteries or cells necessary to power the intended piece of equipment
 - o The net weight of the lithium batteries in the package does not exceed 5 kg.

International (Outside the United States)

Batteries Only, Air Only
(International Air Transport Association (IATA) Packing Instruction 968)

- Batteries must be packaged in a manner to prevent short circuits and separated so that electrically active terminals cannot come into contact with each other.
- The gross weight of the shippable container shall not exceed 2.5 kg.
- The shippable container must be capable of passing a 1.2 m. drop test in any orientation without spillage of

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the contents of the packaging, damage to the batteries inside or shifting of the contents that could lead to short circuit.

- The batteries must be capable of passing the UN Model Regulation T-tests (UN Manual of Tests and Criteria, Part III, Sub-Section 38.3 Lithium Batteries).
- The shippable container must be labeled with the label shown below. The minimum dimensions of the label are 120 mm x 110 mm. The red border is mandatory but the batteries, glass and fire icon can be in black and white.



For customers re-shipping batteries, the telephone numbers (CHEMTREC information) may not be used without a subscription from CHEMTREC.

- Each shipment must be accompanied by a document such as an air waybill with the following:
 - o "This shipment contains Primary Lithium batteries. Do not damage or mishandle the packages. If package is damaged, flammability hazard may exist; batteries must be quarantined, inspected, and repacked."
 - o A telephone number for additional information.

Batteries Only, Surface (Truck/Sea/Rail) Transportation (IMDG/ADR Regulations)

To ship lithium batteries by surface (rail, truck, sea vessel, etc) outside the United States, the shipments must meet the criteria shown below.

- Cell and batteries must meet the requirements of UN Manual of Test and Criteria, Part III, sub-section 38.3.
- Cells and batteries shall be packed in strong outer packagings and inner packagings that completely enclose the cell or battery and protect the batteries from short circuit.
- Each package shall be marked with an indication:
 - o The package contains 'lithium metal' cells or batteries;
 - o The package shall be handled with care and that a flammability hazard exists if the package is damaged;
 - o Information that special procedures shall be followed if the package is damaged and that inspection and possible repackaging is necessary; and
 - o A telephone number of more information.

While not technically required, the IATA label shown below meets the marking requirements listed above for the shippable package. The minimum dimensions of the label are 120 mm x 110 mm. The red border is mandatory but the batteries, glass and fire can be in black and white.

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For customers re-shipping batteries packed in or with equipment, the telephone numbers (CHEMTREC information) may not be used without a subscription from CHEMTREC.

- Each package shall be accompanied separately by a document with:
 - o "This shipment contains Primary Lithium batteries. Do not damage or mishandle the packages. If package is damaged, flammability hazard may exist, batteries must be quarantined, inspected, and repacked."
 - o A telephone number for additional information
- Each package shall be capable of withstanding a 1.2 m drop test in any orientation without damage to the cells or batteries, shifting of contents so as to allow uncontrolled battery to battery or cell-to-cell contact, or release of the contents.
- The maximum weight of a shippable package is 30 kg gross mass.

Batteries Packed With or Contained In Equipment, Air Transportation
(IATA Packing Instructions 969 and 970)

- The batteries must be capable of passing the UN Model Regulation T-tests (UN Manual of Tests and Criteria, Part III, Sub-Section 38.3 Lithium Batteries).
- Cells and batteries must be packed in inner packagings that completely enclose the cell or battery.
- Cells and batteries must be protected so as to prevent short circuits. This includes protection against contact with conductive materials within the same packaging that could lead to a short circuit.
- The maximum number of batteries in each package must be the minimum number required to power the equipment plus two spares.
- For batteries packaged with equipment only, the shippable container must be capable of passing a 1.2 m. drop test in any orientation without spillage of the contents of the packaging, damage to the batteries inside or shifting of the contents that could lead to short circuit. This provision does not apply to batteries packaged inside equipment.
- For batteries contained inside equipment only, the equipment must be equipped with an effective means of preventing accidental activation.
- The shippable container must be labeled with the label shown below. The minimum dimensions of the label are 120 mm x 110 mm. The red border is mandatory but the batteries, glass and fire can be in black and white.

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For customers re-shipping batteries packed in or with equipment, the telephone numbers (CHEMTREC information) may not be used without a subscription from CHEMTREC.

- Each shipment must be accompanied by a document such as an air waybill with an indication that:
 - o "This shipment contains Primary Lithium batteries. Do not damage or mishandle the packages. If package is damaged, flammability hazard may exist, batteries must be quarantined, inspected, and repacked."
 - o A telephone number for additional information

Batteries Contained In or Packed With Equipment
Surface (Truck/Sea/Rail) Transportation (IMDG / ADR Regulations)

To ship lithium batteries packaged with, or inside equipment by surface (rail, truck, sea vessel, etc) outside the United States, the shipments must meet the criteria shown below.

- Cell and batteries must meet the requirements of UN Manual of Test and Criteria, Part III, sub-section 38.3.
- Cells and batteries, except when installed inside equipment, shall be packed in strong outer packagings and inner packagings that completely enclose the cell or battery and protect the batteries from short circuit.
- Cells or batteries installed inside equipment shall be protected from damage and short circuit and the equipment shall be equipped with a means of preventing accidental activation.
- The shippable container must be labeled with:
 - o An indication the package contains 'lithium metal' cells or batteries;
 - o An indication the package shall be handled with care and that a flammability hazard exists if the package is damaged;
 - o An indication that special procedures shall be followed in the event the package is damaged, to include inspection and repacking if necessary; and
 - o A telephone number for additional information.

While not technically required, the IATA label shown below meets the marking requirements listed above for the shippable package. The minimum dimensions of the label are 120 mm x 110 mm. The red border is mandatory but the batteries, glass and fire can be in black and white.

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For customers re-shipping batteries packed in or with equipment, the telephone numbers (CHEMTREC information) may not be used without permission and a subscription from CHEMTREC.

- Each shipment must be accompanied by a shipping document with an indication that:
 - o "This shipment contains Primary Lithium batteries. Do not damage or mishandle the packages. If package is damaged, flammability hazard may exist, batteries must be quarantined, inspected, and repacked."
 - o A telephone number for additional information
- Except for batteries installed inside equipment, each package shall be capable of withstanding a 1.2 m drop test in any orientation without damage to the cells or batteries, shifting of contents so as to allow uncontrolled battery to battery or cell-to-cell contact, or release of the contents.